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***Windsor Air Quality Study***
***L'étude sur la qualité de l'air de Windsor***

Windsor Air Quality Committee | Comité sur la qualité de l'air de Windsor

# Mathematical Modelling and Source Apportionment

## REPORTS OF THE WINDSOR AIR QUALITY STUDY

1: Windsor Air Quality Study : Executive Summary
2: Windsor Air Quality Study : Emission Inventory for Windsor/Detroit Airshed
3: Windsor Air Quality Study : Air Monitoring Activities
4: Windsor Air Quality Study : TAGA 6000 Survey Results
5: Windsor Air Quality Study : Personal Exposure Survey Results
6: Windsor Air Quality Study : Soil and Garden Produce Survey Results
7: Windsor Air Quality Study : Mathematical Modelling/Source Apportionment
8: Windsor Air Quality Study : Health Effects Assessment
9: Windsor Air Quality Study : Plain Language Summary

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# WINDSOR AIR QUALITY STUDY:

# MATHEMATICAL MODELLING

# AND

# SOURCE APPORTIONMENT

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# WINDSOR AIR QUALITY STUDY:

# MATHEMATICAL MODELLING

# AND

# SOURCE APPORTIONMENT

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## Summary

The objectives of this modelling/source apportionment report were to determine: 1) the relative contributions of various source sectors to the modelled air concentrations of the 21 chronic effect compounds for which both U.S. and Canadian emissions data were available; and 2) the spatial distribution of the air concentrations of these compounds across the Windsor area. The report entitled Windsor Air Quality Study: Health Effects Assessment describes the health effects of these compounds and provides information on which contribute most to chronic health risks in Windsor. The information in the modelling report can be integrated with results in the heath assessment report to aid in the development of a cost effective remedial abatement strategy to reduce risks due to ambient air concentrations in the Windsor area.

Since chronic health effects were the concern in the Windsor Air Quality Study, modelling was performed to calculate annual average air concentrations using average emission rates. A year long hourly meteorological data set was used in these calculations. Annual average air concentrations were produced at 102 receptor locations. These receptors included 23 locations where air monitoring occurred with the majority of the remaining receptors in the urban Windsor area and some receptors in the rural area surrounding Windsor.

To provide more confidence in the apportionment of the air concentrations among the source sectors and to determine the relative impacts of the compounds in this study, observed air concentrations were compared with modelled values. The objective was to identify the causes of any model-observation discrepancies and to rectify these problems if possible. Long range transport and/or photochemical production contributions to air concentrations were included and found to be a major part of the air concentrations for carbon tetrachloride, formaldehyde and mercury. If the observed data were considered to be reliable and discrepancies could not be resolved by re-examining the emission inventory, modelled concentrations were multiplied by a 'calibration factor' to provide best agreement with the field data. The agreement found between modelled and observed results was good for most compounds. Of the 21 compounds examined, model results were not changed for six compounds and were adjusted by less than a factor of 2.5 for eight other compounds. These results suggest that the overall emission inventory is an adequate starting point for developing effective abatement strategies. Given the uncertainties in estimating emission rates for the wide range of possible sources as well as the variability in meteorology from year to year and biases/scatter in measurements, the agreement between modelled and measured air concentrations was very good for most of the compounds studied. Two pollutants, chloroform and methylene chloride, had modelled concentrations which were at least a factor of ten less than observations. This appears to be due to missing emissions and correspondingly a source apportionment was not performed for these compounds.

Summaries of the source apportionment of air concentrations averaged over the Windsor area are given in Tables 5.1.1 and 5.1.2 for the Canadian (Windsor and vicinity) sources and U.S. (Detroit and vicinity) sources respectively.

The Windsor Air Quality Study: Health Effects Assessment has identified a number of compounds as contributing significantly to chronic cancer risks and to chronic effects on various body organs and systems due to inhalation. These compounds include chromium, benzene, 1,3-butadiene, formaldehyde, carbon tetrachloride, benzo(a)pyrene and cadmium. For carbon tetrachloride and formaldehyde, long range transport/photochemistry was a dominant contributor to the observed air concentrations. Photochemistry along with long range transport accounts for 60 to 80% of the modelled formaldehyde air concentrations. The modelled contribution from sources in the Detroit area on average Windsor air concentrations were about 58% for cadmium, about 65% for chromium, 67% for benzo(a)pyrene and benzene and about 76% for 1,3-butadiene. Area sources, particularly mobile emissions, were the dominant source sector for benzene(84%), 1,3-butadiene(96%) and benzo(a)pyrene(99%) while the steel industry in Detroit (50%) and the automobile manufacturing sector in Windsor (16%) were the largest contributors to modelled chromium air concentrations. Cadmium air concentrations in the Windsor area had a significant modelled contribution (about 35%) due to road dust from Windsor and Detroit with automobile manufacturing in the Windsor area (27%) and the steel industry in Detroit (13%) having the next largest modelled contribution.

The pattern of modelled air concentrations across Windsor depended on the types of sources of importance for each of the compounds. For example, benzo(a)pyrene and 1,3-butadiene were dominated by emissions from area sources and showed similar contour patterns of air concentrations. The highest values were in the north-west part of Windsor with a gradual reduction in concentrations toward the south-east. For benzene, the contribution to air concentrations due to Windsor industrial sources added to the area source contribution to produce a maximum modelled impact in north-central Windsor. Formaldehyde, which had a contribution from area sources, also showed the highest concentration in the north-west but the added background concentration meant that the decrease of concentrations to the south-east was much less pronounced. Compounds with large contributions from point sources such as chromium and cadmium showed very different air concentration patterns. Both of these compounds have a region with higher modelled air concentrations over the north-central part of Windsor. This was the result of the combined impacts of a number of industries in that area. A source apportionment for receptors located near the maximum modelled concentrations shows a larger percentage contribution from Canadian point sources than was found on average over the greater Windsor area.

The source apportionment and the modelled distribution of air concentrations across Windsor presented in this report can be used together with the results in the Windsor Air Quality Study: Health Effects Assessment Report to provide

information for developing a cost effective remedial abatement strategy to reduce risks due to ambient air concentrations in the Windsor area.

# 1. Introduction

## 1.1 Study Objectives and Components

The concept of a series of urban airshed toxics studies in Ontario was a result of growing concerns in the province over the health impacts of airborne toxics. The urban toxics monitoring program in the United States, which has been underway since the mid-1980s, has shown a wide variety of known and suspected carcinogens in urban environments. Risk assessment analyses for airborne toxics have been carried out in many American cities similar in size and industrial development to Ontario urban communities.

Windsor was selected as the site for Ontario's first urban airshed toxic study because of its history of air quality problems and the monitoring which had already been done in the area. The concerns over the impact of the Detroit incinerator resulted in routine monitoring for a number of volatile and semi-volatile organic substances and heavy metals starting in 1987 (Environment Canada and the Ontario Ministry of Environment and Energy in Canada and, R. F. Weston Inc. and Wayne County in Detroit). In 1990 two more airborne toxic monitoring stations were added in West Windsor.

The objective of these urban air toxic studies in Ontario was to characterize and understand the risks due to airborne toxics and ultimately to effectively reduce the exposure of the population to these compounds.

The Windsor Air Toxics Study was designed to answer the following questions:

1. What are the airborne toxics which might cause worry?

2. What are the levels of airborne toxics in the airshed?

3. What are the major contributing sources for the chemicals of concern?

4. What are the most significant exposure pathways for the chemicals of concern?

5. What are the relative health risks of Windsor citizens resulting from exposure to the airborne toxics?

The answers to these questions were obtained during the period June 1991 through March 1993 by means of an intensified monitoring program, detailed compilation of pollutant emission rates in the Windsor/Detroit airshed, and data analysis using mathematical models and health effects information. The monitoring and emission inventory work involved cooperative efforts with Environment Canada.

The focus of the Windsor Air Toxics Study was on substances with chronic health effects, such as particulate-borne trace metals, and volatile and semi-volatile organic compounds. Many of these substances are known or suspected carcinogens. Pollutants which cause acute effects, such as ozone, sulphur dioxide, or carbon monoxide, were not addressed. These are the subject of other Ministry programs, and are reported on regularly in the Ministry's Annual Air Quality in Ontario reports.

The component parts of the Windsor Air Quality Study were:

1) Ambient air monitoring;

2) Special studies using mobile monitoring (TAGA);

3) Personal exposure assessment;

4) Soil and vegetation sampling;

5) Emission inventories;

6) Dispersion modelling to apportion the impact of various source sectors; and

7) Health effects assessment.

## 1.2 Mathematical Modelling/Source Assessment

Mathematical models were used to link the emissions from sources in the Windsor area (Canada) and the Greater Detroit area (U.S.) with ambient air concentrations of the compounds of concern in this study. Emission data for both Canada and the U.S. were available for twenty-one compounds. Since the toxic compounds included in the Windsor Air Quality Study were those with chronic long term exposure impacts, annual average emission estimates were input into a dispersion model to calculate annual average air concentrations in

the Windsor and vicinity area.

Mathematical modelling provides a practical means of assessing the relative contribution of Canadian and U.S. emission sources as well as the contributions of industry sectors and widespread urban emission sources such as vehicles. To evaluate the potential benefits of any program to abate emissions, it was essential that such a source apportionment be carried out. Model calculations were performed at locations in Windsor, the surrounding rural areas and at the locations of air monitors in the Windsor and Detroit areas. The annual average concentrations for the twenty-one compounds (for which U.S. and Canadian emission data were available) were derived by running a mathematical dispersion model for a year long meteorological data set then averaging over the 8760 hourly values in the year.

Since a primary objective of the Windsor Air Quality Study was to provide the best assessment of impacts due to atmospheric releases of the chemicals of concern and to apportion the contributions to calculated air concentrations among the sources as well as possible, model calculated concentrations were compared with observed data. Differences between the modelled annual average concentrations and observed values were then reconciled if possible. The factors considered when there were model-observation discrepancies included the following:

1. Do model-observation discrepancies vary from one location to another?

2. Are the monitoring results reliable? How much variability is there from year to year and/or site to site?

3. Could long range transport contribute significantly to observed concentrations?

4. Could chemical reactions in the air result in increases or decreases in the species' concentrations?

5. Is dry deposition or precipitation scavenging of the species a significant factor over the tens of kilometres the pollutant might travel from the source to the receptor?

6. What are the main emitters of the pollutant? How reliable are these emission estimates? Could any significant emission categories be missed in the inventory?

It was not always possible to establish the reasons for systematic model-observation discrepancies. If all of the factors listed above had been considered and observed/modelled discrepancies still existed then the modelled results were scaled to agree with observed data. If some of the observed data were felt to be more accurate and/or to have more sensitivity (a lower detection limit), then those data were emphasized in model-observation comparisons. For some compounds, the data from Environment Canada was more extensive and the observations had a lower detection limit than MOEE data. In these cases, the ratio of modelled to observed concentrations at Environment Canada monitors were then given more weight when producing "calibrated model" concentrations.

This combined usage of model results with observed data to identify discrepancies in modelled concentrations and to produce a "calibrated model" output had not been done in the earlier studies of toxics in this airshed, i.e., the Transboundary Toxics Study[1] by U.S. EPA and the International Joint Commission report entitled "Air Quality in the Detroit-Windsor/Port Huron-Sarnia Region"[2]. This analysis provided more confidence in the use of model results to delineate the relative contributions of U.S. and Canadian sources as well as the contributions from various source sectors. Since the calibrated model results would reduce biases in modelled concentrations of the compounds, the relative impacts of the pollutants in the study were also better defined after performing the model-observation analyses.

## 2. Model Used

### 2.1 CAP Dispersion Model

Small scale dispersion models are usually designed to calculate concentrations at locations out to about 30 km downwind of a source(s). Hourly average air concentrations are calculated at fixed receptor locations for the specific meteorological conditions at that hour. If there are many sources in the airshed, the contribution of these sources are added to give the total concentrations at receptor locations. By running such a model for a sequence of hourly average meteorological data, concentrations can be averaged over the time period. For this Windsor Air Quality Study where we were interested in cancer and other chronic risks, annual average air concentrations were calculated. This was accomplished by running a dispersion model developed by the Ministry of Environment and Energy for a year long hourly meteorological data set (i.e., 8760 hours of data).

The air dispersion model used in this study is the CAP model developed by MOEE (Appendix 8, Clean Air Program(CAP)$^3$). This model was developed as a proposed replacement for the dispersion model currently used in Regulation 346 to approve emissions from sources such as industries and institutions. In putting together the CAP model, a significant effort was made to incorporate more recent knowledge of dispersion in the atmosphere and to cover the full range of meteorological conditions which could occur. To accomplish this, different modules were used for specific meteorological conditions. The general categories of meteorological conditions covered by the CAP model are stable (i.e., usually clear skies at night with light winds), neutral (windy and cloudy), convective (daytime with thermal currents created by the sun heating the earth surface) and lakeshore fumigation (during warm season days near large lakes when a lakebreeze transports stable air from over the lake to the convective air mass over the land). The magnitude and location of maximum air concentrations can vary significantly depending on the stability classification given above, the wind speed and the roughness of the surface (i.e., buildings and trees are rough surfaces while grass and water are smooth surfaces).

The model was designed to use standard meteorological data from a weather station along with daytime mixed layer heights derived from an upper air balloon temperature profile. The information used is wind speed and direction (10 m and a higher level), cloud fractional coverage, air temperature, time of day, day of the year, snow

coverage and the daytime mixed layer height. Other information used as input to the modelling package included whether the area was urban or rural, the roughness of the surface and the location of large lakes.

Three general source types were modelled in the Windsor Air Quality Study. The first were emissions from stacks greater than 15 m in height. If there were several stacks on a facility with similar characteristics, the emissions were combined with only one stack modelled. For releases from short stacks (< 15 m), vents or fugitive emissions from facilities, the emissions were assumed to come from a building (i.e., a volume source) with dimensions of 10 m high by 50 m wide. Since the modelling for this study was not designed for detailed assessments around individual industries,treating releases from short stacks as volume sources to give the regional impact was a good approximation. The last source type modelled was area sources. This included emissions from vehicles, fuel combustion, consumer goods, road dust, small industries and commercial establishments etc. The emissions were assumed to occur over a grid where the resolution in terms of grid size varied from 1 km by 1 km in the urban Windsor area to 10 km by 10 km in rural areas remote from Detroit/Windsor. These emissions were modelled as a volume source using the horizontal dimensions of the grid in question to determine the initial horizontal plume spread. The initial vertical plume spread also depended on the horizontal dimensions of the grid (i.e. the plume would have a larger initial vertical spread if the edge of the grid was further from the grid centre).

The annual average concentrations due to each source at all receptors were first calculated. This allowed the contribution of any industrial or area source sector to the overall concentration to be calculated. By inter-comparing these model results with observed data and estimating a background/photochemistry contribution where appropriate, the "calibrated" model results were then a more reliable estimate of the air concentration impacts across the Windsor area.

## 3. Input Data for Dispersion Model

In order to determine the air concentration due to any emission source at a given receptor, three primary data fields are required, namely, the release parameters of the source, the rates at which the pollutants are being emitted and meteorological data. For point sources, the stack parameters required are stack height, diameter, exit velocity and the exit temperature of the gas. For this study, emission rates were based on the assumption that emissions were continuous and the model inputs were based on annual average emissions. Meteorological data requirements are dependent on the model being used. The model used in this study required wind speed and direction, time and day of the year, air temperature, cloud fractional coverage, snow cover, daytime mixed layer height and the surface roughness for each hour in a year.

The following sub-sections describe the input data used in the model:

### 3.1 Emissions

The model requires the rate of emission of a pollutant and its release characteristics. The emission inventories compiled by MOEE in the report, Windsor Air Quality Study: Emission Inventory for Windsor/ Detroit Airshed[4] tabulated these data.

Emission data were compiled by the Emission Inventory Task Force. There were two sets of data; one set comprised of emissions from Detroit and the surrounding areas (Transboundary Toxics Study[1]) and the second set comprised of emission data collected for the city of Windsor and the surrounding areas. Table 3.1.1 lists the pollutants for which emission data were compiled in both Ontario and Michigan. The emission data were compiled for two different type of sources; point sources and area sources. A point source emission inventory refers to individual stationary points of emissions. These emissions can be from elevated stacks or from short stacks or fugitive emissions. Most of the larger industrial plants and institutions fall into this category. The area source inventory contains emission data for a defined grid on a map. Emissions can come from any location within the grid, but it is assumed that they are distributed evenly over the entire grid. For example, emissions from mobile sources, residential and commercial/institutional fuel combustion, small dry cleaning facilities, degreasing operations and rubber and plastic manufacturing plants were tabulated in the area source emission inventory file.

US Transboundary Study Emission Data:

These data were compiled by a consulting company for the US-EPA. The company also updated some of the emission estimates for the Windsor Air Quality Study. The inventory for point and area sources used information from a variety of data bases in its compilation. Some of the input data used goes back as far as 1985 with the most recent data included in the final inventory being 1991 data for the steel and utilities sectors. The grid sizes for area sources and the locations of the point source facilities are given in Figure 3.1.1 ( the grid sizes varied from 2.5 km over the Detroit area to 10 km in areas with lower emission rates). This inventory was used for all except Windsor and vicinity area and point sources.

Since the list of compounds included in the US-EPA study only partly overlapped with the list of 46 compounds in the Windsor Air Quality Study, modelling could only be performed for the 21 pollutants in Table 3.1.1. There was a total of approximately 350 area source grid cells along with about 200 facilities including nearly 2,000 point sources in the inventory. To reduce the computational load to a more manageable level, emissions from stacks on a given facility were combined if the stack characteristics were similar (i.e., stack height) and the sources were within 500 m of one another.

The data bases included information on the industrial or area source sector to which the emissions belonged as well as annual average emission rates and source characteristics. This enabled a sector breakdown of the relative air concentration contributions of groups of Windsor/Detroit and vicinity sources.

Windsor and Vicinity Emission Data:

For the Windsor area shown in Figure 3.1.2, an intensive effort was made to establish a good emission inventory of the toxic compounds in this study. The inventory was compiled from 1990 data with the area sources divided into about 400 grid cells over the greater Windsor area. Each area source grid cell had dimensions of 1 km by 1 km. About 70 facilities, including one in Amhersburg to the south of Windsor, were included in the point source inventory. The factors considered in estimating annual average emission rates for the area sources and the point source facilities included in the inventory are described in the Windsor Air Quality Study: Emission Inventory for Windsor/Detroit Airshed[4]. Where possible, area source emission estimates were checked by using both a "bottom up" and "top down" calculation. This means that provincial production and/or chemical usage figures were apportioned to the Windsor area for a top down emission estimate to be compared with detailed emission estimates (i.e., bottom up). For example, traffic count data give bottom up emission data while fuel usage is the start point for top down emission calculations.

The comparisons made between modelled concentrations using these input emissions and observed data provided a good check on the overall emission total and, to a lesser extent, on the distribution of the emissions.

## 3.2 Receptor Locations

Since a primary objective of this study was to link the emission sources with air concentrations in the Windsor area, model calculations were performed primarily in the Greater Windsor area (receptor locations). To provide the best analyses of the impacts of the pollutants studied and the source sector apportionment, modelled concentrations should be compared with observed results. For this reason, receptors were also located at monitor locations in the Windsor/Detroit areas. Figures 3.2.1 and 3.2.2 show the 102 receptors used in this study. This included a total of 12 U.S. and 11 Canadian monitoring locations. Of the remaining receptors about 20 were located in the rural areas south and east of Windsor with the remainder in the urban Windsor area.

## 3.3 Meteorological Data

As discussed in Section 2, the dispersion model was run for a year long sequence of hourly average meteorological data. Annual average concentrations were obtained at the model receptor sites by averaging over the 8760 hours in the meteorological data set.

The data required by the model's meteorological preprocessor were:

i) wind speed and direction;
ii) air temperature;
iii) time of day and day of year to calculate solar radiation;
iv) snow coverage (yes or no);
v) daytime mixed layer height obtained from an upper air temperature profile and surface temperatures; and
vi) fractional cloud coverage.

Additional data needed to calculate the model dispersion parameters were the roughness of the surface, whether the location was urban or rural and whether or not the terrain was complex. A detailed description of these factors is included in Appendix 8: Clean Air Program[3].

Using the above data, the meteorological preprocessor calculates the

atmospheric stability as a continuous function covering stable, neutral, convective and lakeshore fumigation conditions.

The meteorological data used in this study were based on 1989 information. Since the emission data ranged from 1985 to 1991, the modelling could not simulate a specific year for both emissions and meteorology. The meteorological data set based on 1989 data is used to produce one example of an annual average concentration pattern over the Greater Windsor area. The upper air temperature profile and thus the daytime mixed layer heights were obtained using data from Flint, Michigan. Wind speed and direction data at the 10 m level were obtained from the Windsor Airport while data at an 85 m tower in Courtwright, Ontario provided a higher level wind speed. Figure 3.3.1 gives the wind rose for the 1989 Windsor Airport data. This figure shows the predominence of south through west-south-west wind directions and the low occurence of easterly and south-easterly wind directions found in long term average data. In 1989, the northerly wind component was a little more frequent than usual. Surface temperatures and cloud coverage also made use of Windsor Airport data. Snow coverage was based on the daily 1 inch and 6 inch snow lines reported by the U.S. National Oceanographic and Atmospheric Administration.

Since wind direction frequencies as well as the other meteorological parameters can vary from year to year, the annual average air concentrations predicted by the model will have a degree of variability due to meteorology. The observations against which model results were compared, covered a range of years from 1988 through 1992. Model-observation comparisons used the latest reliable observed data in assessing discrepancies. Meteorological variability is one factor which can result in observed annual average concentrations differing from year to year. Given possible meteorological variability from year to year and the fact that the emission estimates were sometimes for earlier years than the observed data, model-observation differences of up to 30 to 50 percent are not necessarily significant.

## 4. Dispersion Model - Observation Comparisons

The basic objective of the Windsor Air Quality Study is to provide a comprehensive assessment of the impacts due to atmospheric releases of compounds with chronic effects including known or suspected carcinogens. Dispersion modelling is used to apportion the ambient air concentration levels among the various Canadian (Windsor and vicinity) and U.S. (Detroit and vicinity) emission sources. To provide the best estimates of the ambient air concentrations and the apportionment of these impacts, modelled concentrations are compared with observed data and, if possible, the values are reconciled. These "calibrated" model results could then be used in assessing the benefits derived from various pollution abatement programs.

The approach to model-observation comparisons were iterative as emission data for the Windsor and Detroit areas were improved over the study time period. Earlier model-observation comparisons provided input to decide which parts of the emission inventory required most attention. The factors considered in the model-observation comparisons were given earlier in Section 1.2. Where possible, the reason for any discrepancy was identified. If long range transport and/or photochemistry were important for a compound then local observed data were used along with data at remote sites to estimate this contribution to ambient air concentrations. Once background contributions have been taken into account and all efforts have been made to improve and verify emission estimates there could still be discrepancies between modelled and observed ambient air concentrations. When the observed data were considered to be reliable, then modelled concentrations were scaled to correspond to the observed data unless the discrepancy was too large (i.e., greater than a factor of 5). If the discrepacy was greater than a factor of 5, no source apportionment assessment was made for that compound.

The observed data used in the comparison with model results are described in the report Windsor Air Quality Study: Air Monitoring Activities[5]. Model-observation comparisons emphasize the latest reliable obsevations although data from 1988 to 1992 were considered. Other monitoring data in Ontario and elsewhere in Eastern North America were used in estimating background/photochemistry concentrations for some compounds and to help assess the reliability of the monitoring data in the Windsor area.

Table 4.1 summarizes the background/photochemistry concentrations and the factors derived to adjust the model results to best correspond to observed data. A brief description of the model-observation comparisons for each of the twenty-one compounds follows:

### Arsenic

The only arsenic data available were at two sites in Windsor. These data were obtained with a low volume sampler using an impregnated filter designed to capture vapour phase arsenic as well as particulate arsenic. The model results were about 3

times higher than the observed data. One possible cause of a model overestimate of arsenic ambient air concentrations and overestimates for several other heavy metals is that the emission factors used are for total emissions. Arsenic contained in larger particles would settle out close to the source (i.e., particle diameters greater than about 20 $\mu$m). The particle size distributions would vary from source to source. It is not clear that this factor could account for the model - observation differences by itself. Other possibilities could include overestimates of emissions from some source sectors.

Beryllium

Most of the observed data were below the detection limit. Since the model results were similar to the few observed values above the detection limit, the model results appear to be high. The model results were reduced by a factor of 2 to account for the overestimate. The observed data were not sufficient to do better than this estimated correction factor.

Cadmium

When model results from the first version of the emission inventory were compared to observed data, model results were too high compared to Windsor monitors and too low compared to Detroit monitors. Road dust emission estimates appeared to be partly responsible for these results. About half of road dust emissions are associated with particle sizes above 20 $\mu$m(US-EPA[6]). These particles will likely settle out close to the source. On the other hand, the original inventory did not include road dust in the U.S. The final emission inventory used in the model runs reduced Canadian road dust emissions by a factor of two and used the same emission factor for road dust in the U.S.. Based on the relative importance of road dust shown in the emission inventory for Windsor, cadmium was the only compound where U.S. road dust emissions were added. The result was no systematic difference in model and observed concentrations in the U.S. and an overprediction of concentrations in Windsor by about 50%. Based on this comparatively small difference in model and observed concentrations, no change was made to the model results.

Chromium

Model results for total chromium compared reasonably well with average observed concentrations. However, since most of the observed data were below the detection limit, the comparison could not be done precisely. Overall model results were similar to US observations while the modelled values were high compared to Windsor and Walpole Island monitoring results by about a factor of two. Modelled results were reduced by 40% to best compare to observed data. To calculate chromium VI concentrations, the total chromium results are multiplied by 0.2. This fraction is based on monitoring of chromium VI and total chromium in Windsor as well as literature values (Windsor Air Quality Study: Personal Exposure Survey Results[7]; Sheenhan et. al.[8], 1988).

Lead

Modelled lead concentrations were higher than the 1991 observed data. For the monitors in the Detroit area, the modelling results were typically about 70% higher, while the model results were three times the observed values in Windsor. Lead is one compound for which monitoring data have shown substantial decreases in concentrations in recent years. The overestimate in modelled lead concentrations could be related to the particle size question described earlier as well as improvements in area source emission rates (i.e., vehicle emissions from the Windsor area and other area sources from the Detroit area were the major contributors to the modelled results). Model results are reduced by a factor of 2½.

Nickel

A large percentage of the observed nickel data in Windsor in 1991 were below the detection limit (i.e., 75 to 95%). Observed nickel concentrations in Detroit were twice as large as those in Windsor. There was no systematic difference between model and monitor results in the Detroit area but for Windsor, the model results were about three times the observed concentrations. Overall model results were reduced by a factor of two as a balance between the data sets.

Mercury

Mercury can occur primarily in three forms in emissions and monitoring data: elemental mercury, divalent mercury (i.e., Hg0 or $HgCl_2$) and mercury attached to particles. Most observed data shows more than 95% of the airborne mercury to be elemental mercury which has a half life in the atmosphere estimated to be many months. Correspondingly, there is a long range transport component of the gaseous mercury measurements in Windsor. Measured concentrations of gaseous mercury were taken over a period of about one week at various sites in Windsor and were reported in Windsor Air Quality Study: TAGA 6000 Survey Results[9]. When the wind direction was such that the monitoring was not downwind of Detroit or point sources in Windsor, the average concentration was about 1.5 ng/m$^3$. This is similar to background values measured at sites from Wisconsin through to Ontario. Therefore, the long range transport background concentration used is 1.5 ng/m$^3$. Taking into account wind direction frequencies, the modelled average concentration of 0.4 to 1 ng/m$^3$ is consistent with the residual mercury measured by the TAGA 6000 (i.e. after subtracting off the background concentration). There was no adjustment of the modelled mercury concentrations.

1,3-Butadiene

This compound undergoes chemical decomposition at a rate which depends on the amount of sunlight, the air temperature and other chemical concentrations in the atmosphere. Modelled concentrations were, however, a little higher than observed data

at one U.S. monitoring site but were more than three times the observed values in Windsor. Taking all observed data into account, the modelled 1,3-butadiene concentrations were reduced by a factor of 2½.

Benzene

Although both 1,3-butadiene and benzene have vehicle emissions as a major contributor to ambient air concentrations, modelled results were too high for 1,3-butadiene and too low for benzene. Since the model run was the same for the two compounds and the observed data are consistent with other urban centres, it suggests that the discrepancies are primarily related to the emission estimates. The chemical decomposition of 1,3-butadiene could account for part of the variance in model-observation discrepancy between these two compounds.

In Detroit modelled benzene concentrations were about half of the observed values. Some of these observed data are from 1988 rather than 1991. The 1991 Windsor observed data were about 70% higher than modelled concentrations. Since the model-observation comparisons were similar in Windsor and Detroit, the model results were increased by 70%.

Formaldehyde

Formaldehyde is a reactive hydrocarbon which can be produced photochemically. Correspondingly there would be a long range transport/photochemical component to observed concentrations in Windsor. Formaldehyde measurements were only available at two fixed monitoring sites in Windsor. At the University Ave. site, the two full years of data for 1990 and 1991 gave average concentrations of 1.8 and 4.0 $\mu g/m^3$, respectively (Windsor Air Quality Study: Air Monitoring Activities[5]). A half year of data in 1991 at the College Park station showed much higher concentrations (8.0 $\mu g/m^3$). This could indicate some local source impacts near the College Park station but the data set was too short for a definitive conclusion. Concentrations at remote sites in Ontario are typically 1 to 2 $\mu g/m^3$. Correspondingly, a long range transport/photochemical concentration of at least 1.5 $\mu g/m^3$ was considered to be appropriate for this urban area. Since modelled concentrations of formaldehyde in Windsor added to a 1.5 $\mu g/m^3$ background concentration gave a modelled concentration of about 2.3 $\mu g/m^3$ at the University Ave. station, the modelled results were consistent with the limited amount of measured data.

Carbon Tetrachloride

This compound is very insoluble and correspondingly is only slowly removed from the atmosphere by dry deposition or wet scavenging processes. The residence time of carbon tetrachloride in the atmosphere is many months. Almost all of what is observed in air concentrations in Windsor/Detroit is due to long range transport. This is shown by comparing observed data at Walpole Island, a relatively rural site, to Windsor data. Both

show concentrations of 0.8 to 0.9 $\mu g/m^3$. A monitoring site in Detroit recorded 1.4 $\mu g/m^3$ in 1991. A background concentration of 1 $\mu g/m^3$ was chosen with no adjustment of the modelled concentrations due to local emissions which accounted for only about 1% of the observed concentrations.

Perchloroethylene

The 1991 observed perchloroethylene data were about 30% lower than 1990 data for the Windsor area. Although the model results show no systematic bias with respect to the 1990 data they were about 50% higher than the 1991 data. This change in monitoring results could be due partially to meteorological differences from year to year but there might be some emission changes as well. Although the model-observation discrepacy was not very large, model results were nevertheless reduced by 30% to best correspond to the 1991 observed data.

Trichloroethylene

Comparisons of observed data with model results for trichlorethylene show model values to be high by 50 to 100%. To account for the observed data, model results were reduced by 40%.

Acrylonitrile

There were no observations of acrylonitrile above the detection limit. Since the model results were about a tenth of the observation detection limit, they were not inconsistent with the observations. With the available information, the model results were not altered.

Benzo(a)Pyrene

When modelled air concentrations of benzo(a)pyrene were compared with 1990-1991 observations in Detroit, the model results were usually 2 to 3 times higher. For the comparison in Windsor, more reliance was placed on data from Environment Canada since the MOEE data varied by a factor of 2 to 10 from year to year. The modelled concentrations were 3 or 4 times higher than observed values for these 1991 data. The model results are then multiplied by 0.3 to give "calibrated" benzo(a)pyrene concentrations.

Vinyl Chloride

As was the case for acrylonitrile, monitoring results were almost entirely non-detects and the model results were below the detection limit. Since there is no information to indicate the model results are incorrect, these values were left as is.

PCBs

Comparisons of model and observed PCB concentrations indicated that emissions were underestimated. Results at monitoring sites run by R.F. Weston in Detroit had

concentrations 8 to 10 times the modelled concentrations. Environment Canada data for Windsor were about 3 times the modelled results but there was variability from year to year of a factor of 2 or 3. At Walpole Island, the monitoring data were about 8 times higher than the modelled values. Overall, the model results were increased by a factor of 5 to be comparable with the observed data. It should be kept in mind that the model-observation discrepancies might indicate sources not in the inventory as well as variability in monitoring results and the accuracy of emissions from inventoried sources.

Dioxins and Furans

The model-monitor comparisons for dioxins and furans were similar to those for PCBs. For both of these compounds, the U.S. emission data included only point sources with more than 1 lb/year of emissions. This could result in some sources which contribute measurably to observed concentrations not being in the inventory. For Windsor, an area source contribution due to wood burning stoves was included while the U.S. Transboundary emission data did not include this source sector. Because of greater sensitivity, the Environment Canada data at Windsor and Walpole Island were the primary reference used in model-observation comparisons. The modelled calculations were low by a factor of 2 to 4. Overall model results were increased by a factor of 3 to correspond to observed data. As mentioned, this could be in part due to sources not included in the emission inventory.

Chloroform

The observed concentrations were much larger than modelled values (i.e., 10 to 40 times larger). Since the observed data in Windsor were similar to data in urban U.S. locations, the monitoring data appears to be reliable. Observed data at rural and remote sites are much smaller than urban values suggesting that long range transport is not a major contributor to observed results and there is no indication of photochemical production of chloroform in ambient air. That means that missing emissions were the most likely cause of the discrepancies. The question of missing chloroform emissions was discussed in the Windsor Air Quality Study: Emission Inventory for the Windsor/Detroit Airshed[4] but no resolution of problem was achieved. Correspondingly, chloroform was not included in the source apportionment analyses.

Methylene Chloride

As was found for chloroform, the observed results were much larger than modelled concentrations (i.e., about 10 times higher). The most likely reason for this discrepancy is missing sources of emissions. This problem was described in the emission inventory report. Since the model results were out of line with observations by such a large factor and the reason for the discrepancy could not be resolved, the modelled results for this compound were not used in the source apportionment.

Model/Emission Estimates of Air Concentrations

Overall the model-observation comparisons summarized in Table 4.1 indicate that the emission data set was of reasonable quality. These model results showed that the emission data is a good starting point to plan and assess the costs and benifits of various emission reduction strategies. Of the 21 compounds examined, only chloroform and methylene chloride results indicated major problems with the emission inventory. There was no systematic bias apparent for 6 of the compounds with 12 of the 21 pollutants adjusted by a factor of 2 or less.

Long range transport and/or photochemical concentrations were significant or dominant for three of the compounds; carbon tetrachloride, formaldehyde and mercury. For these compounds, the modelling of the contribution of local direct emissions appears to be in line with observed values once the background concentration was considered.

## 5. Air Concentrations Source Apportionment

### 5.1 Source Apportionment for Calibrated Modelled Concentrations

Calibrated model runs have been performed to assess the relative contribution of Detroit and vicinity sources (U.S.) and Windsor and vicinity sources (Canadian) to air concentrations in Windsor. The impact of industrial and area source sectors have been delineated in this analysis. These calculations were performed for the receptor locations described in Section 3.2.

The sources are apportioned into the following groups:

U.S. Point Sources
U.S. Area Sources
Canadian Point Sources
Canadian Area Sources

The point and area source sectors presented are:

**Point:**
Steel, foundries and coke manufacturers (STEEL)
Automobile manufacturing industries (AUTO)
Incinerators
Power generation (UTILITIES)
Petroleum refiners (PETROLEUM)
Chromium platers (CHROM)
Other.

**Area:**
Mobile sources (MOBILE)
Residential and commercial fuel combustion (FUEL COMB)
Dry cleaners
Road dust (ROAD)
Others (including small industries)

Results are presented as the average impact over the Windsor area shown in Figure 3.1.2. For benzene, 1,3-butadiene, formaldehyde, benzo(a)pyrene, chromium, cadmium and mercury contour plots of annual average air concentrations have been produced to indicate where higher values occur. These seven pollutants include many of the compounds showing higher chronic risks in the Windsor Air Quality Study: Health Effects Assessment Report[10]. Pie charts and bar charts have been used to show the sector breakdown of the air concentrations for the above seven compounds averaged over the Windsor area. The major uncertainty in the contour plots,

pie charts and bar charts presented was in the distribution of the emissions among the source sectors and across the model domain. The modelled contour patterns would also change somewhat from year to year depending on the frequency of occurence of wind directions and other meteorological conditions. Contour patterns are the combined result of all sources in the model domain. Several point sources could combine with emissions from area sources to give higher concentrations over a part of the Windsor area. For all of the compounds in the study, the source apportionment results are summarized in Tables 5.1.1 and 5.1.2.

The following is a brief description of the air concentrations and the sectoral impacts for the compounds in this study.

Chromium

On average over the Windsor area, nearly 90% of the total chromium air concentrations come from point sources, with the U.S. contribution modelled to be more than twice the Canadian impact. This is shown in Figure 5.1.1. Figures 5.1.2 and 5.1.3 give the sector breakdown of the area and point sources respectively. Fuel combustion accounts for most of the area source concentrations while the steel industry and chromium plating are the dominant point sources of U.S. chromium. The Canadian point source chromium came primarily from the automotive industry with significant contributions from other industries including metal fabricators.

A contour plot of total chromium air concentrations over Windsor, Figure 5.1.4, shows a general decrease in concentrations from about 10 $ng/m^3$ in Detroit to 2 $ng/m^3$ in east Windsor with regions in central Windsor modelled to be above 10 $ng/m^3$.

Cadmium

Overall U.S. and Canadian contributions to Windsor cadmium concentrations were about equal. U.S. area sources, mainly road dust, accounted for above 35% of the air concentrations on average while the Canadian automotive industry accounts for most of the modelled 30% contribution from Canadian point sources. Cadmium from road dust emitted in Windsor was also a significant contributor to the modelled concentrations. Figures 5.1.5, 5.1.6 and 5.1.7 give the U.S. - Canadian breakdown of average impacts and the sector source apportionment.

Figure 5.1.8 shows a similar contour pattern to that for chromium with a region in central Windsor having elevated cadmium concentrations in the model runs.

Mercury

As shown on Figure 5.1.9, long range transport of mercury was estimated to

account for about 80% of annual average concentrations over Windsor in general. This was due to the long lifetime of elemental mercury in the atmosphere. The largest contribution to Windsor mercury concentrations from local sources come from incinerators in the U.S. (i.e., Figures 5.1.10 and 5.1.11). The contour plot, Figure 5.1.12, indicates the impact of a large U.S. incinerator on the north-west Windsor area.

Benzene

Figure 5.1.13 depicts the U.S.- Canadian apportionment of air concentrations in Windsor. Area sources were overwhelmingly dominant with U.S. area sources contributing about 2/3 of the Windsor modelled average air concentrations. As shown in Figure 5.1.14, mobile sources provide the largest portion of U.S. and Canadian area source contributions. The breakdown of point source sector contributions to air concentrations is provided on Figure 5.1.15. The contour plot for benzene (Figure 5.1.16) shows concentrations to be generally higher in the north-west with a gradual decrease in modelled concentrations to the south-east away from the Canada - U.S. border. In the north-central part of Windsor there are higher modelled concentrations which result from local industries adding to the region wide impact of the mobile sources.

1,3-Butadiene

The apportionment of sources of 1,3-butadiene is similar to that of benzene. The dominance of area sources, particularly mobile sources, was more pronounced for 1,3-butadiene than it was for benzene. U.S. area sources account for more than 2/3 of the 1,3-butadiene observed in Windsor. Larger industries and institutions (i.e., point sources) were a comparatively small contributor of 1,3-butadiene concentrations on average for the Windsor urban area. These results are shown in Figures 5.1.17, 5.1.18 and 5.1.19. The contour plot of calibrated model results, Figure 5.1.20, shows the highest values in north-west Windsor.

Formaldehyde

As discussed earlier, photochemistry and long range transport provided a significant fraction of the formaldehyde observed in the Windsor area. Using data for rural areas, the estimated contribution of background concentrations to the total observed formaldehyde was at least 75%. Of the direct local emissions contribution to air concentrations, the mobile sector was the largest contributor. Figures 5.1.21, 5.1.22 and 5.1.23 depict the source apportionment for formaldehyde. The contour pattern (Figure 5.1.24) is similar to 1,3-butadiene except that the background concentration results in a much slower decrease of concentrations to the south-east part of Windsor.

Benzo(a)Pyrene

The model results show more than 99% of the impact for benzo(a)pyrene comes

from area sources. The U.S. contributes about 2/3 of the Windsor air concentrations on average with mobile sources and fuel combustion being the main emitters of benzo(a)pyrene in both the U.S. and Canada. Again the contour pattern shows highest modelled concentrations for Windsor in the north-west with a gradual decrease in concentrations toward the eastern side of Windsor. Figures 5.1.25, 5.1.26, 5.1.27 and 5.1.28 depict the source apportionment and the pattern of modelled air concentrations for benzo(a)pyrene.

Dioxins and Furans

As discussed in Chapter 4, the emission inventory for the U.S. excludes any source with less than 1 lbs of emissions per year. The only point source which remains in the U.S. inventory was the Detroit Resource Recovery Incinerator. In Windsor, the only dioxin and furan point sources identified were from two small hospital incinerators. However, emissions from wood burning stoves were included in the Windsor emission inventory but not in the US Transboundary emission data. As shown in Table 5.1.2, the U.S. incinerator in the inventory accounted for about 83% of the dioxin and 68% of the furan calculated air concentrations in Windsor. Because of the emission inventory limitations, this is probably not a true indication of the source attribution although the U.S. incinerator nevertheless accounted for a significant percentage of the observed dioxin and furan in Windsor [Dann 1991[11]].

Carbon Tetrachloride

The local Detroit and Windsor emissions of carbon tetrachloride are part of the global emissions of this substance which are responsible for the observed long range transport concentration. However, these local emissions had only a small percentage impact on the air concentrations observed in Windsor.

Arsenic

Tables 5.1.1 and 5.1.2 present the sector breakdown of the average arsenic concentrations over Windsor. Canadian area sources and U.S. point sources accounted for most of the modelled impact. Waste incineration and minor industrial sources accounted for the area source contribution while the automotive sector, the steel industry and metal fabrication were significant contributors to the U.S. point source impact.

Beryllium

U.S. point sources were the dominant contributors to beryllium concentrations modelled for Windsor. Automobile manufacturing was the largest single sector.

Lead

Canadian and U.S. area sources represent about 35% each of the model Windsor air concentrations. Mobile sources were responsible for most of the Canadian impact while waste incineration was the major contributor to the U.S. sources. U.S. mobile sources were less significant because lead was phased out as a gasoline additive earlier in the U.S.. Lead is no longer used as a gasoline additive in Ontario but it was still part of the Windsor emissions developed for 1990.

Nickel

The modelled air concentrations were about half from Canadian sources and half from U.S. sources. Fuel combustion represented the largest single source sector with the automobile industry being the next most important.

Acrylonitrile

Point sources were entirely responsible for the modelled acrylonitrile concentrations with the U.S. contribution, mostly from the steel industry, at about 55% of the total modelled air concentrations. The automobile industry was the only sector in the Canadian emission inventory.

Perchloroethylene

This solvent is used mostly in dry cleaning operations. Most of these operations are considered as area sources but some larger dry cleaning plants were included as point sources. Canadian and U.S. contributions were of similar size.

Trichloroethylene

Emissions from the U.S. accounted for 95% of the modelled air concentrations in Windsor. Degreasing operations in the automobile manufacturing sector and other smaller industries were the primary usage of this solvent.

Vinyl Chloride

The modelled impact was almost entirely from U.S. area sources. The sector which contributes most to these emissions was the chemical production industry.

Polychlorinated Biphenols (PCBs)

Emissions of PCBs in the inventory for the Detroit and Windsor regions were all from point sources. The U.S. automobile sector was the largest contributor to the modelled concentrations (about 90%).

In summary, all of the results discussed above are for an average over the urban Windsor area shown in Figure 3.1.2. Because of specific concerns in west Windsor about the impact of U.S. sources, particularly from the Zug Island area, on air concentrations of some compounds, we have also done a source apportionment averaging over only receptors in west Windsor for benzene and benzo(a)pyrene. Although the concentrations were somewhat larger in west Windsor as indicated by the contour plots in Figures 5.1.16 and 5.1.28, the percentage contribution from different source sectors were similar to the average over all of urban Windsor.

## 5.2 Impact of New Great Lake Steel Coke Oven Battery

A new coke oven battery began operations in the fall of 1992 at Great Lakes Steel. Emissions of benzene and benzo(a)pyrene from this source were estimated using the permit limits on the annual emissions. These emissions were small compared to the total benzene and benzo(a)pyrene emissions in the study area. As a result, the impact of this facility on air concentrations in Windsor are very small. Figures 5.2.1 and 5.2.2 show contour plots of the air concentration impact due to this coke oven battery. Comparing these results with Figures 5.1.16 and 5.1.28 for overall benzene and benzo(a)pyrene concentrations shows the small impact of this source assuming it meets the permitted emission limits.

## 6. Summary/Conclusions

The objectives of this modelling/source apportionment report were to determine: 1) the relative contributions of various source sectors to the modelled air concentrations of the 21 chronic effect compounds for which both U.S. and Canadian emissions data were available; and 2) the spatial distribution of the air concentrations of these compounds across the Windsor area.

Since chronic health effects were the concern in the Windsor Air Quality Study, modelling was performed to calculate annual average air concentrations using average emission rates. A year long hourly meteorological data set was used in these calculations. Annual average air concentrations were produced at 102 receptor locations. These receptors included 23 locations where air monitoring occurred with the majority of the remaining receptors in the urban Windsor area and some receptors in the rural area surrounding Windsor.

To provide more confidence in the apportionment of the air concentrations among the source sectors and to determine the relative impacts of the compounds in this study, observed air concentrations were compared with modelled values. The objective was to identify the causes of any model-observation discrepancies and to rectify these problems if possible. Long range transport and/or photochemical production contributions to air concentrations were included and found to be a major part of the air concentrations for carbon tetrachloride, formaldehyde and mercury. If the observed data were considered to be reliable and discrepancies could not be resolved by re-examining the emission inventory, modelled concentrations were multiplied by a 'calibration factor' to provide best agreement with the field data. The agreement found between modelled and observed results was good for most compounds. Of the 21 compounds examined, model results were not changed for six compounds and were adjusted by less than a factor of 2.5 for eight other compounds. These results suggest that the overall emission inventory is an adequate starting point for developing effective abatement strategies. Given the uncertainties in estimating emission rates for the wide range of possible sources as well as the variability in meteorology from year to year and biases/scatter in measurements, the agreement between modelled and measured air concentrations was very good for most of the compounds studied. Two pollutants, chloroform and methylene chloride, had modelled concentrations which were at least a factor of ten less than observations. This appears to be due to missing emissions and correspondingly a source apportionment was not performed for these compounds.

Summaries of the source apportionment of air concentrations averaged over the Windsor area are given in Tables 5.1.1 and 5.1.2 for the Canadian (Windsor and vicinity) sources and U.S. (Detroit and vicinity) sources respectively.

The Windsor Air Quality Study: Health Effects Assessment[10] has identified a number of compounds as contributing significantly to chronic cancer risks and to chronic effects on various body organs and systems due to inhalation. These compounds include chromium, benzene, 1,3-butadiene, formaldehyde, carbon tetrachloride, benzo(a)pyrene and cadmium. For carbon tetrachloride and formaldehyde, long range transport/photochemistry was a dominant contributor to the observed air concentrations. Photochemistry along with long range transport accounts for 60 to 80% of the modelled formaldehyde air concentrations. The modelled contribution from sources in the Detroit area on average Windsor air concentrations were about 58% for cadmium, about 65% for chromium, 67% for benzo(a)pyrene and benzene and about 76% for 1,3-butadiene. Area sources, particularly mobile emissions, were the dominant source sector for benzene(84%), 1,3-butadiene(96%) and benzo(a)pyrene(99%) while the steel industry in Detroit (50%) and the automobile manufacturing sector in Windsor (16%) were the largest contributors to modelled chromium air concentrations. Cadmium air concentrations in the Windsor area had a significant modelled contribution (about 35%) due to road dust from Windsor and Detroit with automobile manufacturing in the Windsor area (27%) and the steel industry in Detroit (13%) having the next largest modelled contribution.

The pattern of modelled air concentrations across Windsor depended on the types of sources of importance for each of the compounds. For example, benzo(a)pyrene and 1,3-butadiene were dominated by emissions from area sources and showed similar contour patterns of air concentrations. The highest values were in the north-west part of Windsor with a gradual reduction in concentrations toward the south-east. For benzene, the contribution to air concentrations due to Windsor industrial sources added to the area source contribution to produce a maximum modelled impact in north-central Windsor. Formaldehyde, which had a contribution from area sources, also showed the highest concentration in the north-west but the added background concentration meant that the decrease of concentrations to the south-east was much less pronounced. Compounds with large contributions from point sources such as chromium and cadmium showed very different air concentration patterns. Both of these compounds have a region with higher modelled air concentrations over the north-central part of Windsor. This is the result of the combined impacts of a number of industries in that area. A source apportionment for receptors located near the maximum modelled concentrations shows a larger percentage contribution from Canadian point sources than was found on average over the greater Windsor area.

The source apportionment and the modelled distribution of air concentrations across Windsor presented in this report can be used together with the results in the Windsor Air Quality Study: Health Effects Assessment Report to provide information for developing a cost effective remedial abatement strategy to reduce risks due to ambient air concentrations in the Windsor area.

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## TABLE 3.1.1

## LIST OF MODELLED POLLUTANTS

ARSENIC

BERYLLIUM

CADMIUM

LEAD

NICKEL

MERCURY

BENZENE

1,3-BUTADIENE

FORMALDEHYDE

CARBON TETRACHLORIDE

VINYL CHLORIDE

BENZO(A)PYRENE

PCBs

DIOXINs

FURANs

ACRYLONITRILE

PERCHLOROETHYLENE

TRICHLOROETHYLENE

CHLOROFORM

METHYLENE CHLORIDE

| TABLE 4.1 | | |
|---|---|---|
| FACTORS USED TO PRODUCE CALIBRATED MODEL | | |
| COMPOUND | MULTIPLICATION FACTOR | BACKGROUND CONCENTRATION |
| ARSENIC | 0.35 | |
| BERYLLIUM | 0.5 | |
| CADMIUM | 1 | |
| CHROMIUM | 0.6 | |
| LEAD | 0.4 | |
| NICKEL | 0.5 | |
| MERCURY | 1 | 1.5 $ng/m^3$ |
| BENZENE | 1.7 | |
| 1,3-BUTADIENE | 0.4 | |
| FORMALDEHYDE | 1 | 1.5 $\mu g/m^3$ |
| CARBON TETRACHLORIDE | 1 | 1.0 $\mu g/m^3$ |
| ACRYLONITRILE | 1 | |
| PERCHLOROETHYLENE | 0.7 | |
| TRICHLOROETHYLENE | 0.6 | |
| VINYL CHLORIDE | 1 | |
| BENZO(A)PYRENE | 0.3 | |
| PCBs | 5 | |
| DIOXINs | 3 | |
| FURANs | 3 | |
| CHLOROFORM* | > 20 | |
| METHYLENE CHLORIDE* | 10 | |

The background concentrations were due to long range transport and/or photochemistry. The multiplication factor was used to bring the model/emission results in overall agreement with measured air concentrations when sufficient reliable observed data was available.

* For chloroform and methylene chloride model/observation comparisons indicate that either the measurements are not correct or that most of the emissions were missing from the inventory.

TABLE 5.1.1

SUMMARY OF PERCENTAGE CONTRIBUTION TO GROUND LEVEL CONCENTRATIONS DUE TO ONTARIO SOURCES FROM WINDSOR AND VICINITY

| POLLUTANT | MOTOR VEHICLE MANUF. | STEEL, COKE | MOBILE SOURCES | UTILTIES & OTHER FUEL COMB. | OTHER INDUSTRIAL | OTHER AREA |
|---|---|---|---|---|---|---|
| ARSENIC | 15 | - | - | - | 1 | 38 |
| BERYLLIUM | - | - | - | - | 12 | - |
| CADMIUM | 27 | - | - | - | 2 | 13 |
| CHROMIUM | 16 | 1 | 2 | 7 | 9 | - |
| LEAD | 11 | 1 | 33 | - | 5 | 2 |
| NICKEL | 19 | 1 | 6 | 21 | 5 | - |
| MERCURY * | - | - | - | - | 3 | 1 |
| BENZENE | 8 | - | 17 | 3 | 2 | 3 |
| 1,3-BUTADIENE | - | - | 16 | - | - | 8 |
| FORMALDEHYDE * | - | - | 7 | 1 | - | - |
| CARBON TETRACHLORIDE * | - | - | - | - | - | - |
| VINYL CHLORIDE | - | - | - | - | - | 1 |
| BENZO(A)PYRENE | - | - | 12 | 21 | - | - |
| PCBs | - | - | - | - | - | - |
| DIOXINs | - | - | - | 10 | - | 7 |
| FURANs | - | - | - | 32 | - | - |
| ACRYLONITRILE | 45 | - | - | - | - | - |
| PERCHLORO-ETHYLENE | 1 | - | - | - | 17 | 38 |
| TRICHOLORO-ETHYLENE | - | - | - | - | - | 5 |

* These compounds have a Long Range Transport and/or photochemical contribution to the air concentrations in Windsor.

| TABLE 5.1.2 | | | | | | |
|---|---|---|---|---|---|---|
| SUMMARY OF PERCENTAGE CONTRIBUTION TO GROUND LEVEL CONCENTRATIONS DUE TO MICHIGAN SOURCES FROM DETROIT AND VICINITY | | | | | | |
| POLLUTANT | MOTOR VEHICLE MANUF. | STEEL, COKE | MOBILE SOURCES | UTILITIES & OTHER FUEL COMB. | OTHER INDUSTRIAL | OTHER AREA |
| ARSENIC | 11 | 10 | - | 2 | 19 | 4 |
| BERYLLIUM | 37 | - | - | - | 51 | - |
| CADMIUM | 3 | 13 | - | - | 6 | 36 |
| CHROMIUM | 1 | 50 | - | 3 | 10 | 1 |
| LEAD | 3 | 11 | 2 | - | 1 | 31 |
| NICKEL | 11 | 11 | - | 11 | 15 | - |
| MERCURY * | - | - | - | - | 13 | 3 |
| BENZENE | 1 | 2 | 31 | 6 | 3 | 24 |
| 1,3-BUTADIENE | 1 | - | 45 | - | 3 | 27 |
| FORMALDEHYDE * | - | - | 7 | - | 7 | 3 |
| CARBON TETRACHLORIDE * | - | - | - | - | - | - |
| VINYL CHLORIDE | - | - | - | - | - | 99 |
| BENZO(A)PYRENE | - | - | 44 | 22 | 1 | - |
| PCBs | 89 | - | - | - | 11 | - |
| DIOXINs | - | - | - | - | 83 | - |
| FURANs | - | - | - | - | 68 | - |
| ACRYLONITRILE | - | 45 | - | - | 10 | - |
| PERCHLORO-ETHYLENE | 2 | 1 | - | - | - | 41 |
| TRICHOLORO-ETHYLENE | 27 | 4 | - | - | 11 | 53 |

* These compounds have a Long Range Transport and/or photochemical contribution to the air concentrations in Windsor.

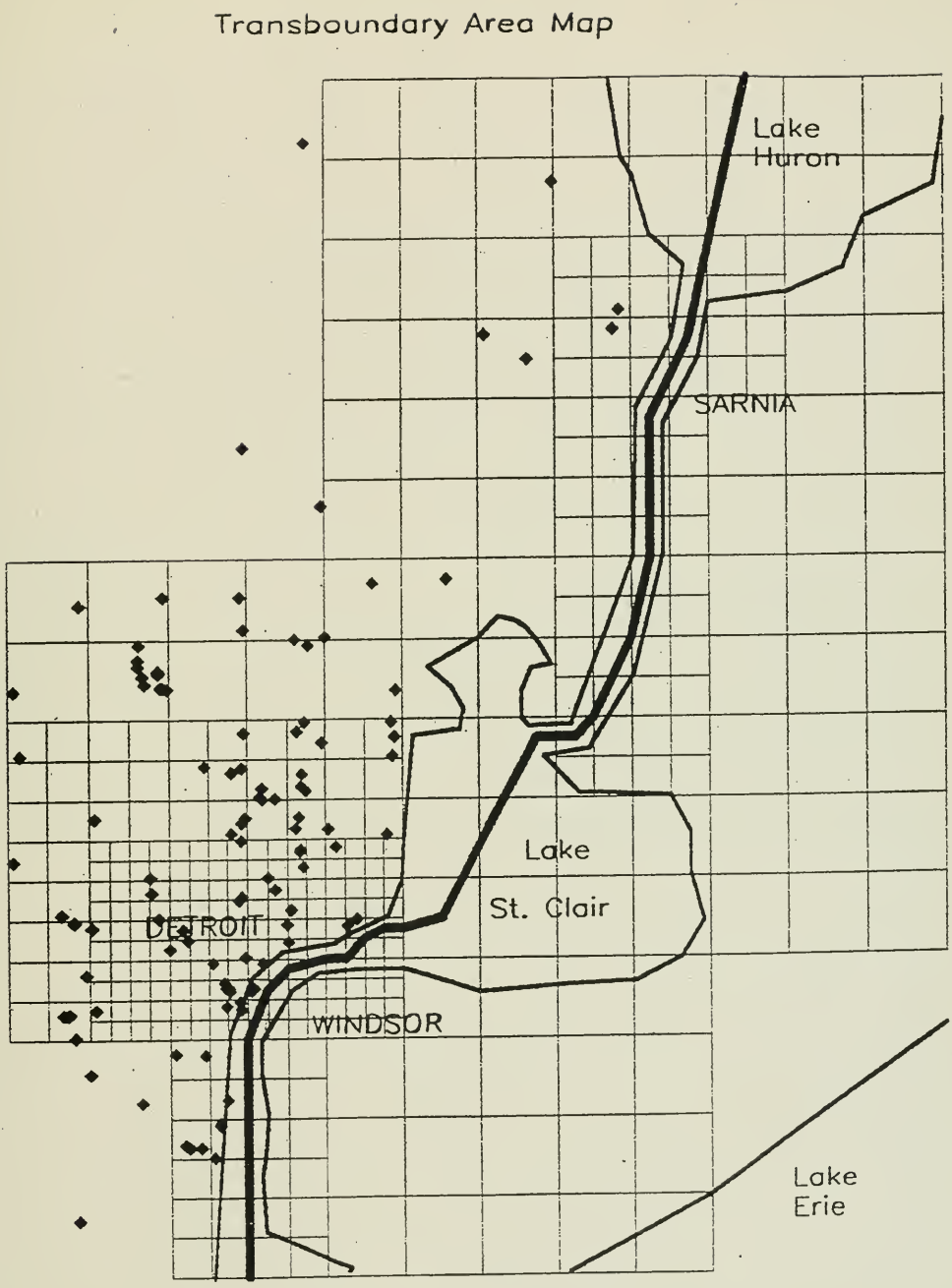



FIG 3.1.1: Spatial Distribution of US Point and Area Sources

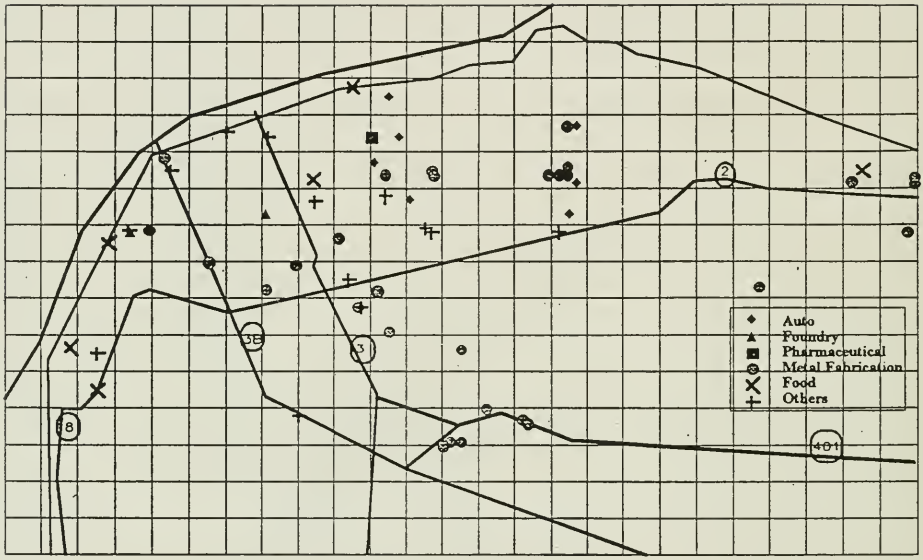



FIG 3.1.2: Spatial Distribution of Windsor Point and Area Sources

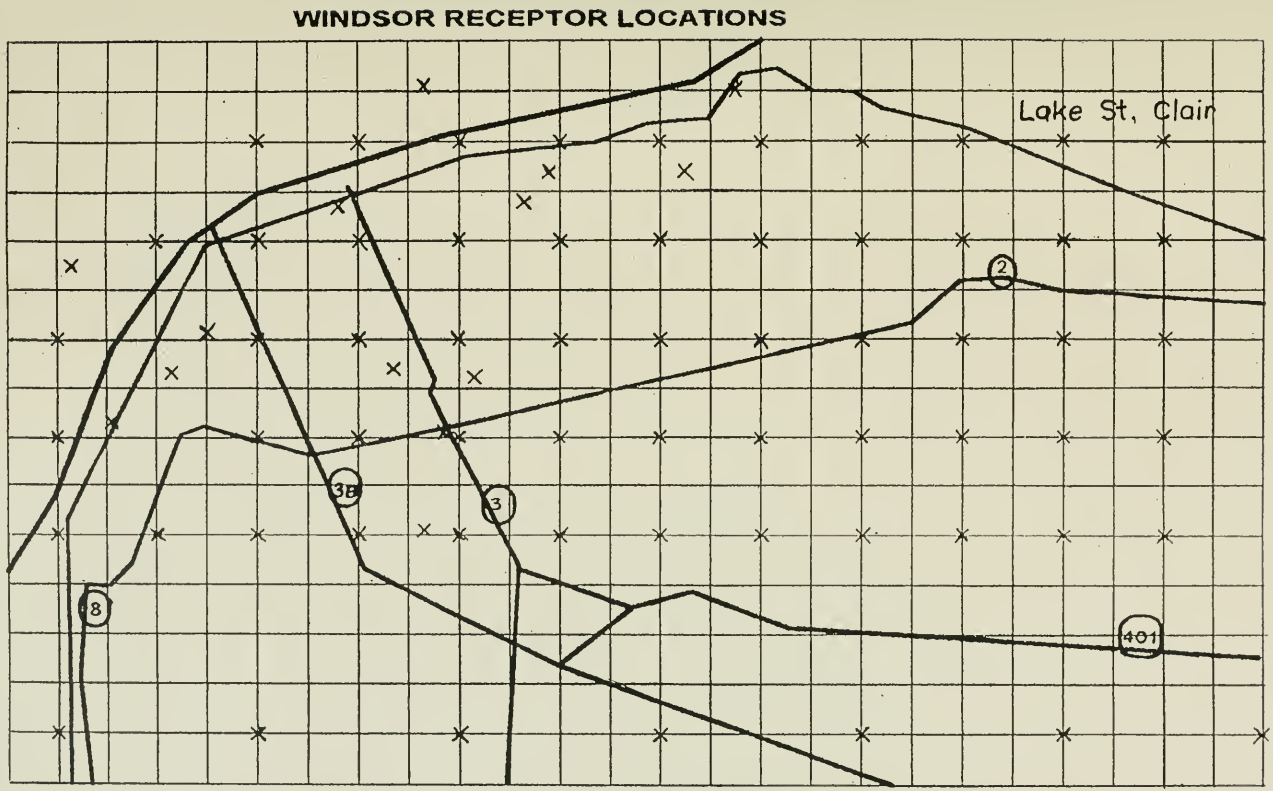



Fig 3.2.1: Windsor Region Receptor Locations

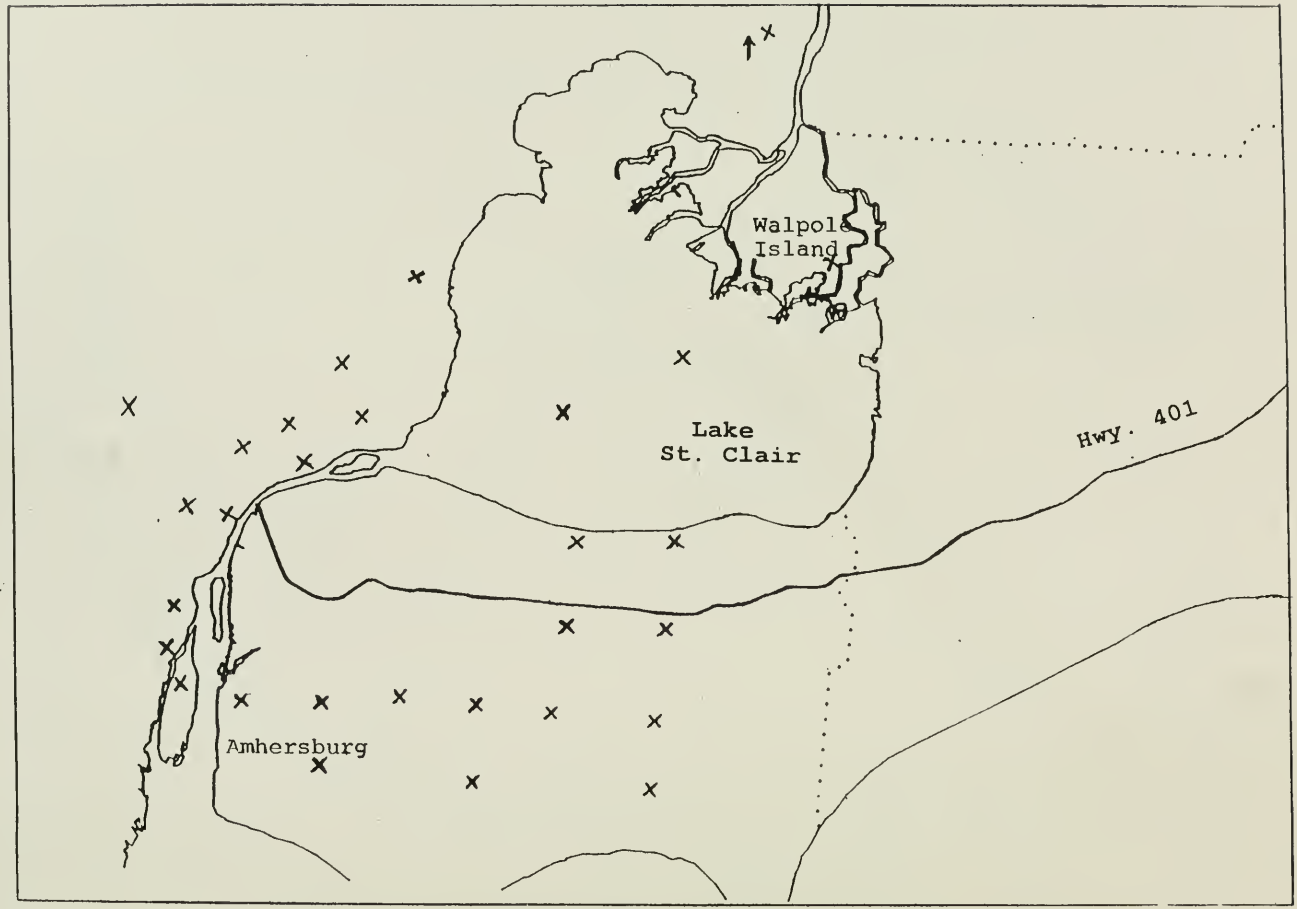



Fig. 3.2.2 : Receptor Locactions Outside Urban Windsor Area

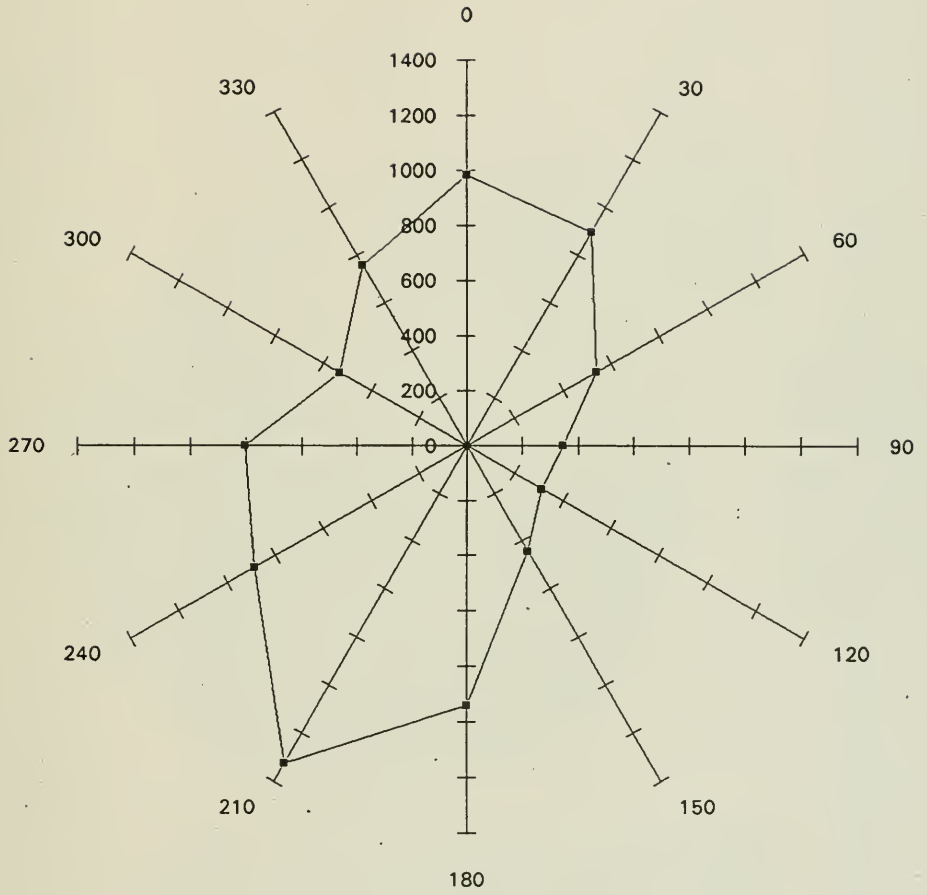
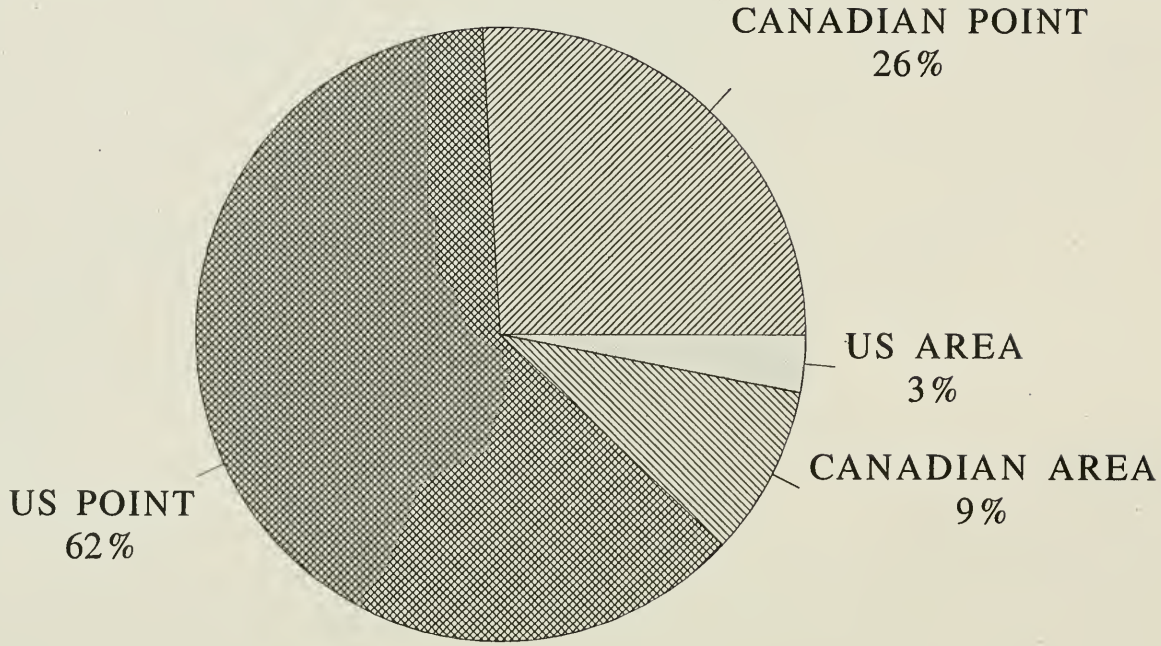
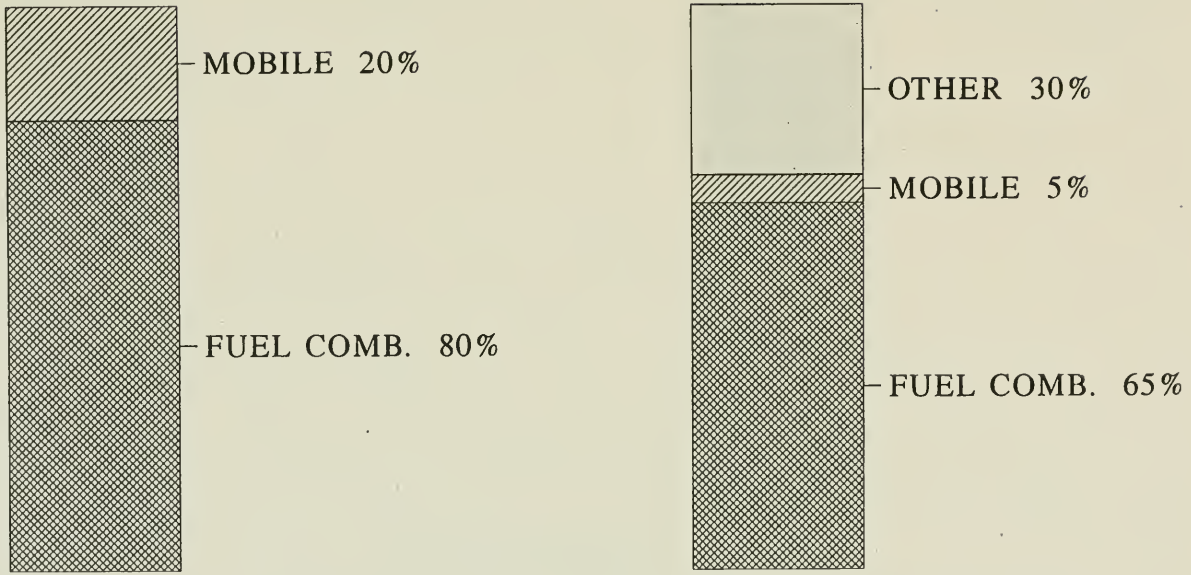



Fig. 3.3.1 : Wind Rose for Windsor Airport Data(10m) 1989

# FIG 5.1.1
# AIR CONCENTRATION IMPACT IN WINDSOR
# CHROMIUM



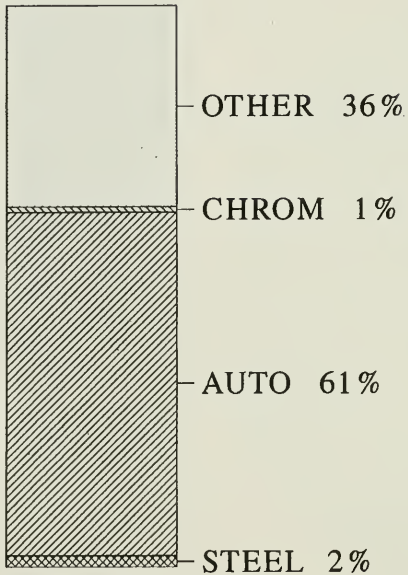
# FIG 5.1.2
# US AND CANADIAN AREA SOURCE SECTORS
## (AIR CONCENTRATION IMPACT IN WINDSOR)
## CHROMIUM



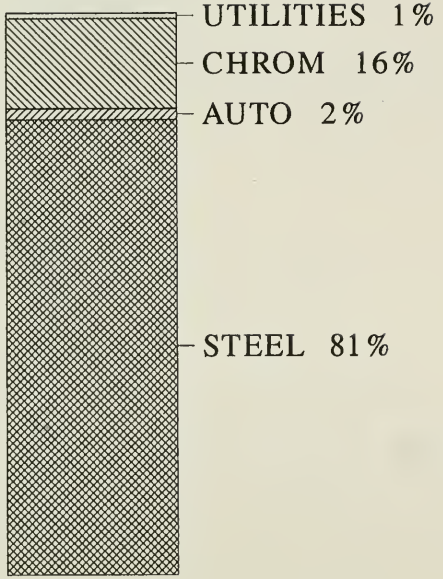

CANADIAN
(9% of total impact)

US
(3% of total impact)

# FIG 5.1.3
# US AND CANADIAN POINT SOURCE SECTORS
## (AIR CONCENTRATION IMPACT IN WINDSOR)
## CHROMIUM



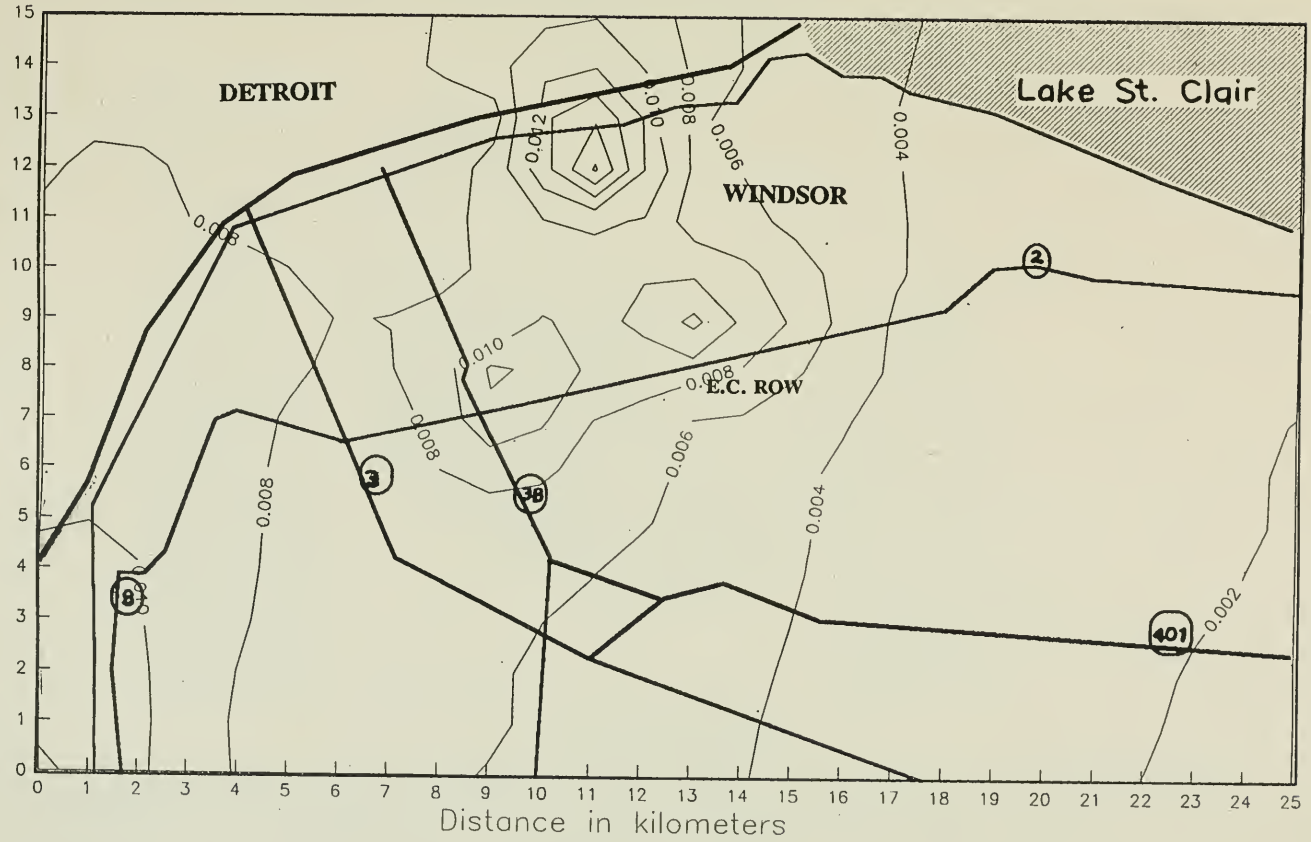

CANADIAN
(26% of total impact)



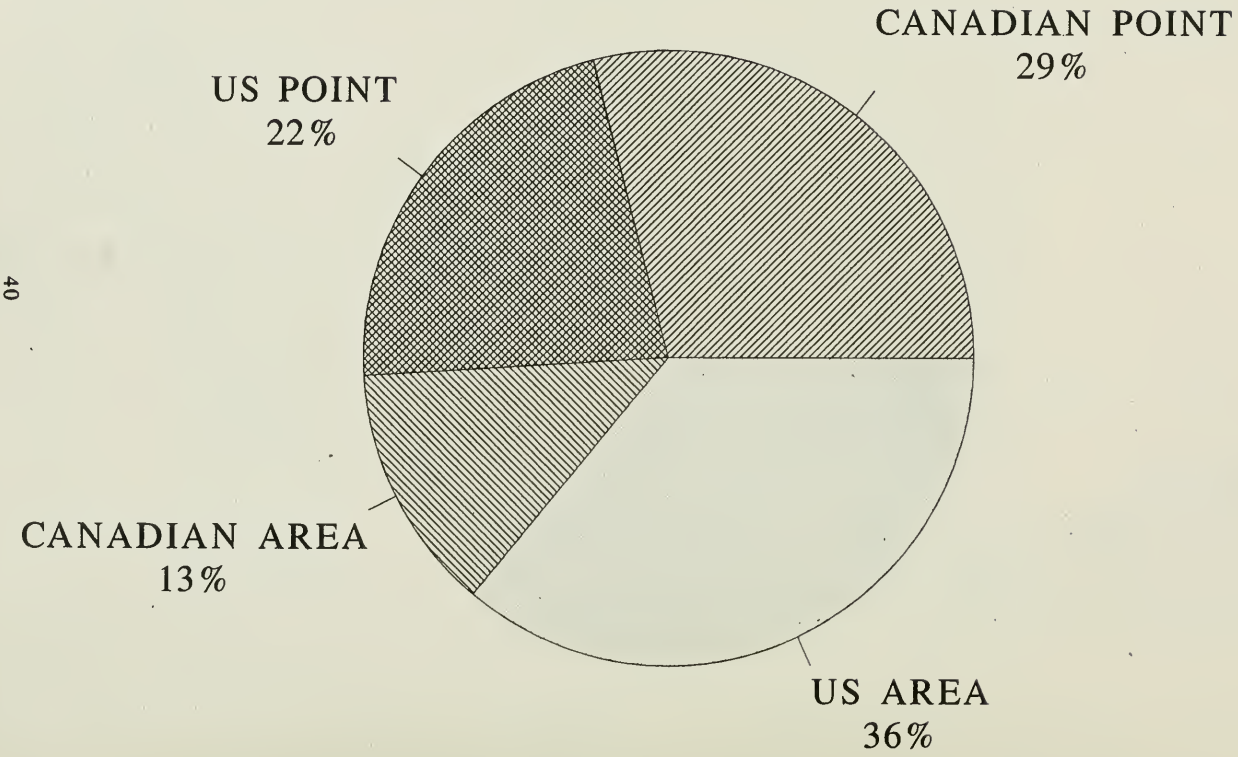

US
(62% of total impact)

## Fig 5.1.4

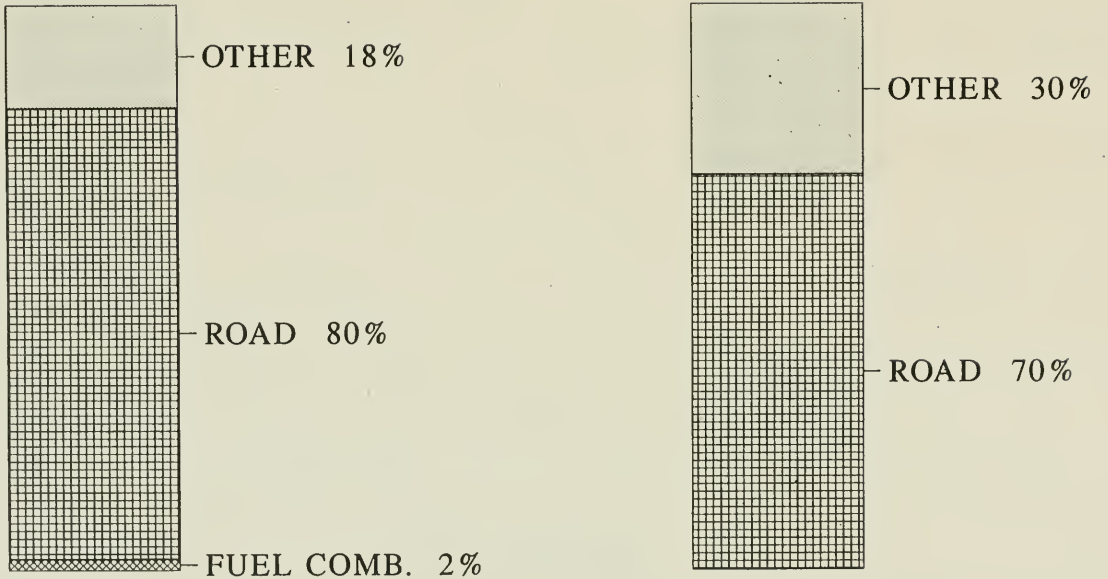
Contours of Chromium Air Concentrations in Windsor



# FIG 5.1.5
# AIR CONCENTRATION IMPACT IN WINDSOR
# CADMIUM



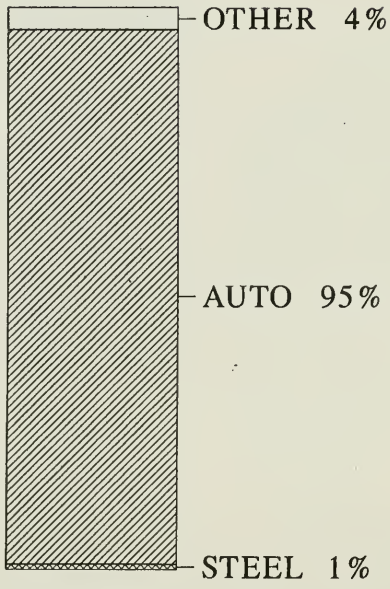
# FIG 5.1.6
# US AND CANADIAN AREA SOURCE SECTORS
## (AIR CONCENTRATION IMPACT IN WINDSOR)
## CADMIUM



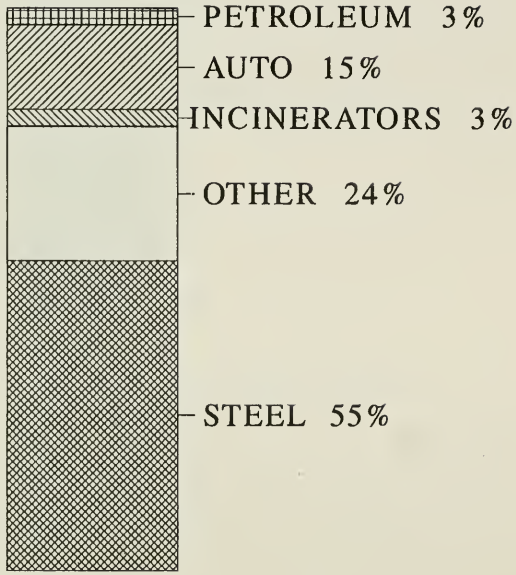

CANADIAN
(13% of total impact)

US
(36% of total impact)

# FIG 5.1.7
# US AND CANADIAN POINT SOURCE SECTORS
# (AIR CONCENTRATION IMPACT IN WINDSOR)
# CADMIUM



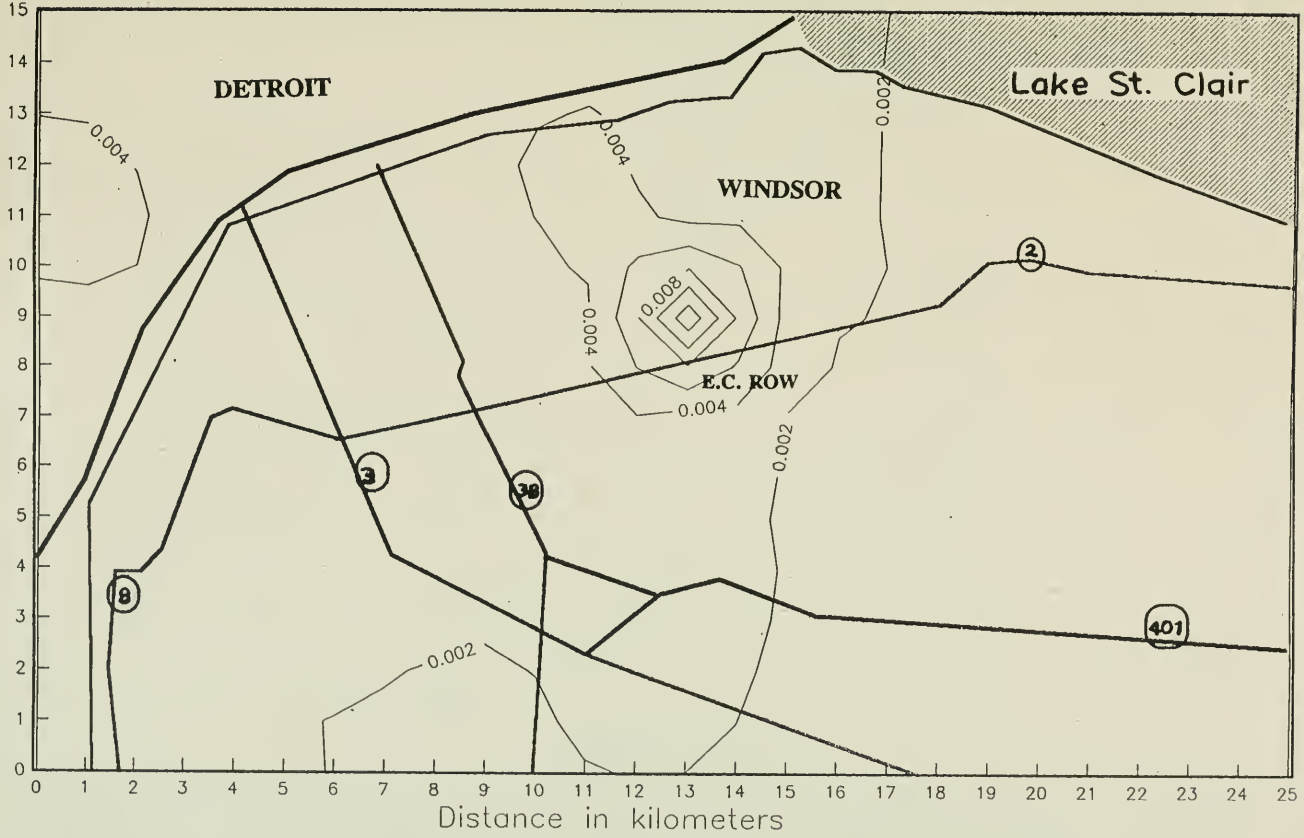

CANADIAN
(29% of total impact)



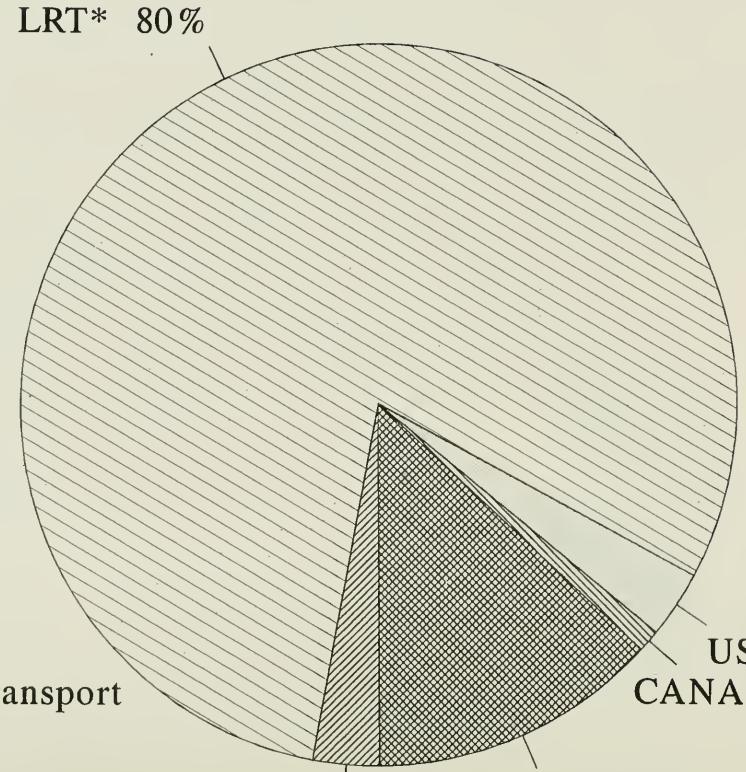

US
(22% of total impact)

## Fig 5.1.8

Contours of Cadmium Air Concentrations in Windsor

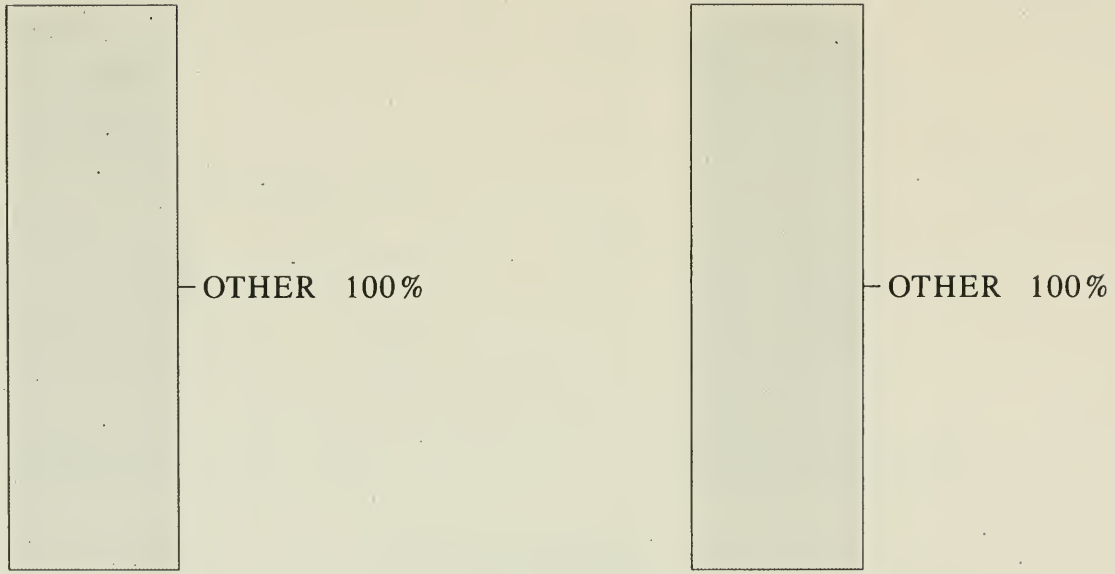


# FIG 5.1.9
# AIR CONCENTRATION IMPACT IN WINDSOR
## MERCURY




* Long Range Transport

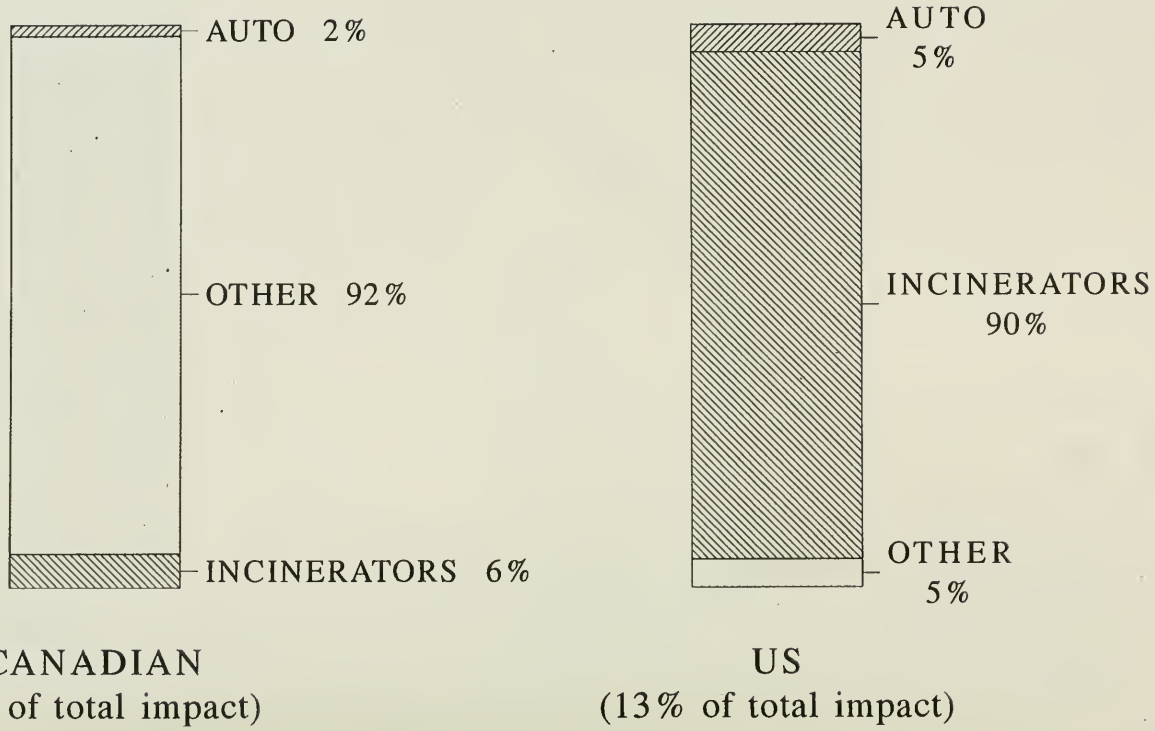
# FIG 5.1.10
# US AND CANADIAN AREA SOURCE SECTORS
## (AIR CONCENTRATION IMPACT IN WINDSOR)
## MERCURY




CANADIAN
(1% of total impact)

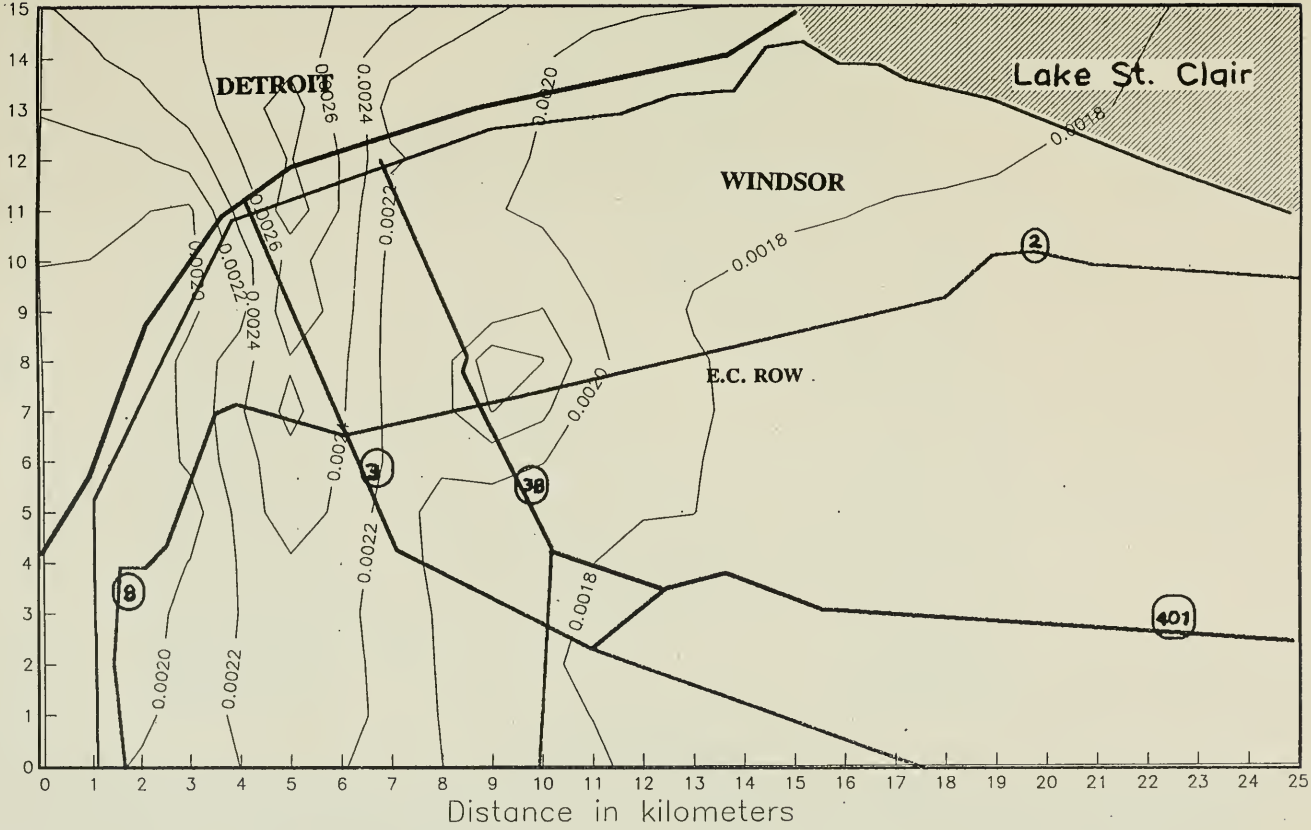
US
(3% of total impact)

# FIG 5.1.11
# US AND CANADIAN POINT SOURCE SECTORS
# (AIR CONCENTRATION IMPACT IN WINDSOR)
# MERCURY

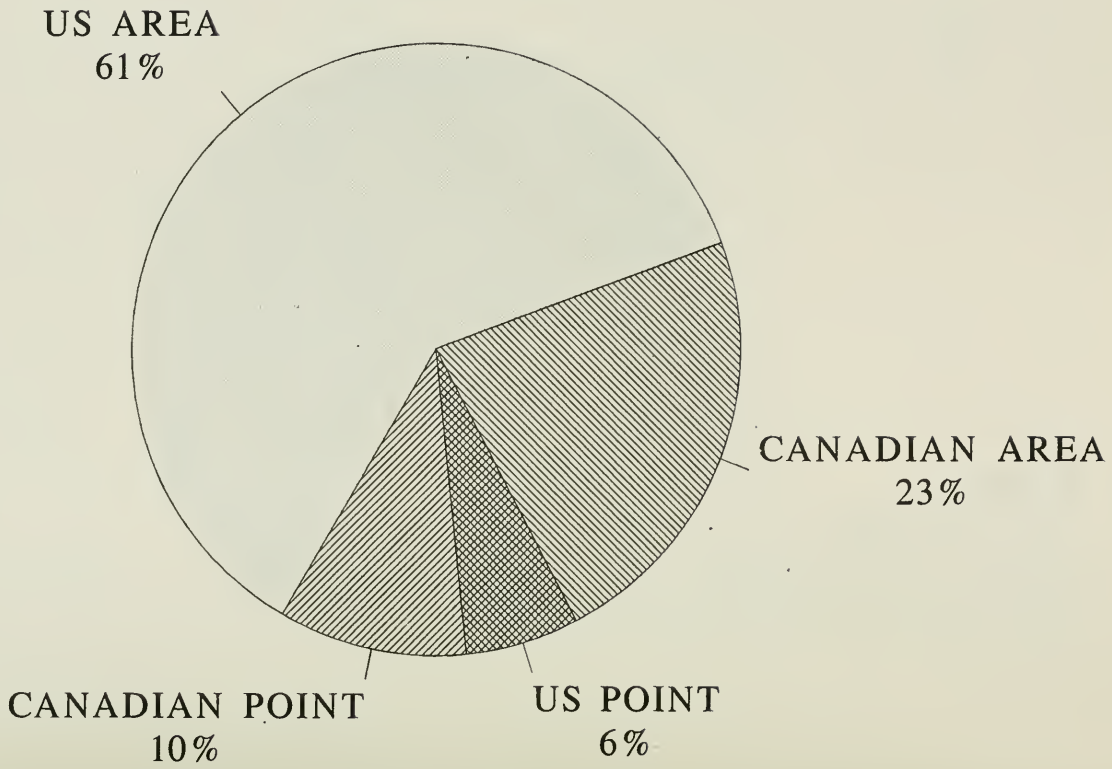


# Fig 5.1.12

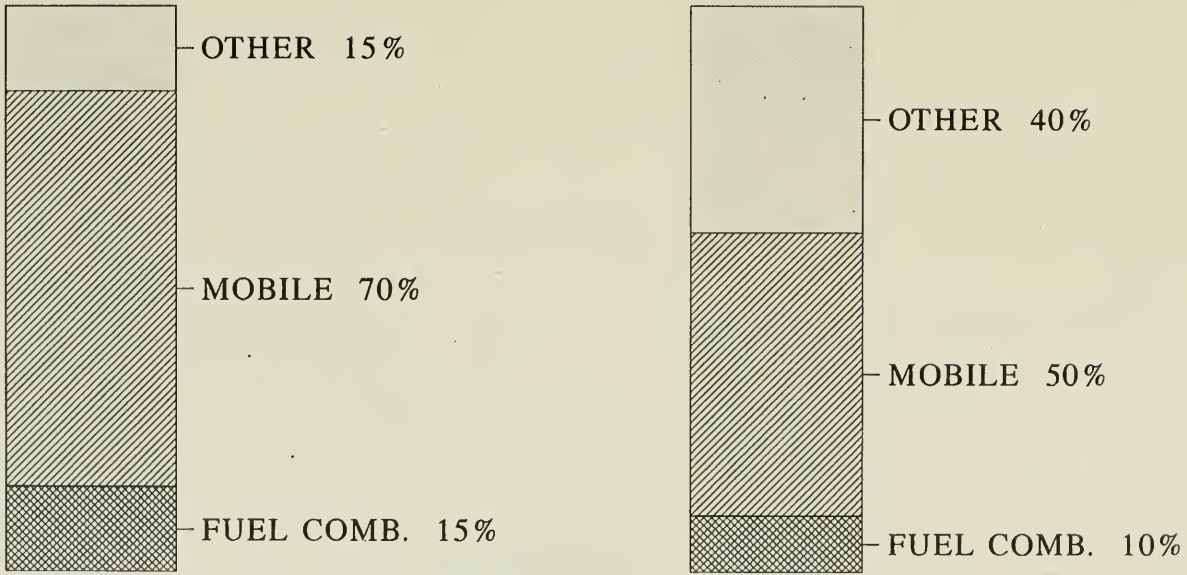
Contours of Mercury Air Concentrations in Windsor



# FIG 5.1.13
# AIR CONCENTRATION IMPACT IN WINDSOR
## BENZENE



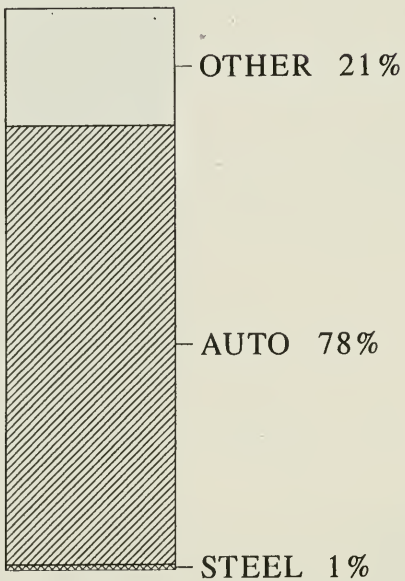
# FIG 5.1.14
# US AND CANADIAN AREA SOURCE SECTORS
# (AIR CONCENTRATION IMPACT IN WINDSOR)
# BENZENE



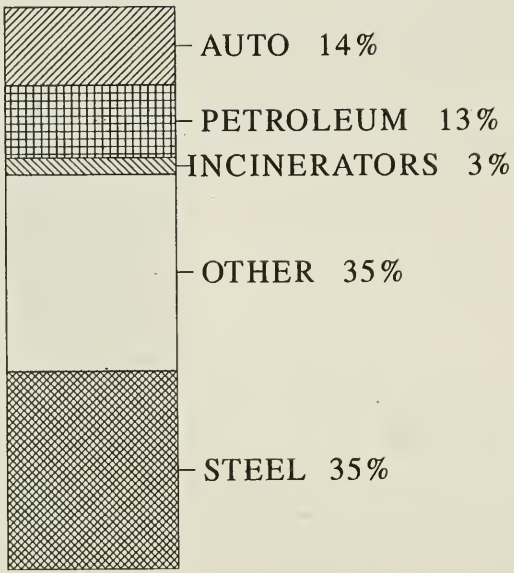

CANADIAN
(23% of total impact)

US
(61% of total impact)

# FIG 5.1.15
# US AND CANADIAN POINT SOURCE SECTORS
## (AIR CONCENTRATION IMPACT IN WINDSOR)
## BENZENE

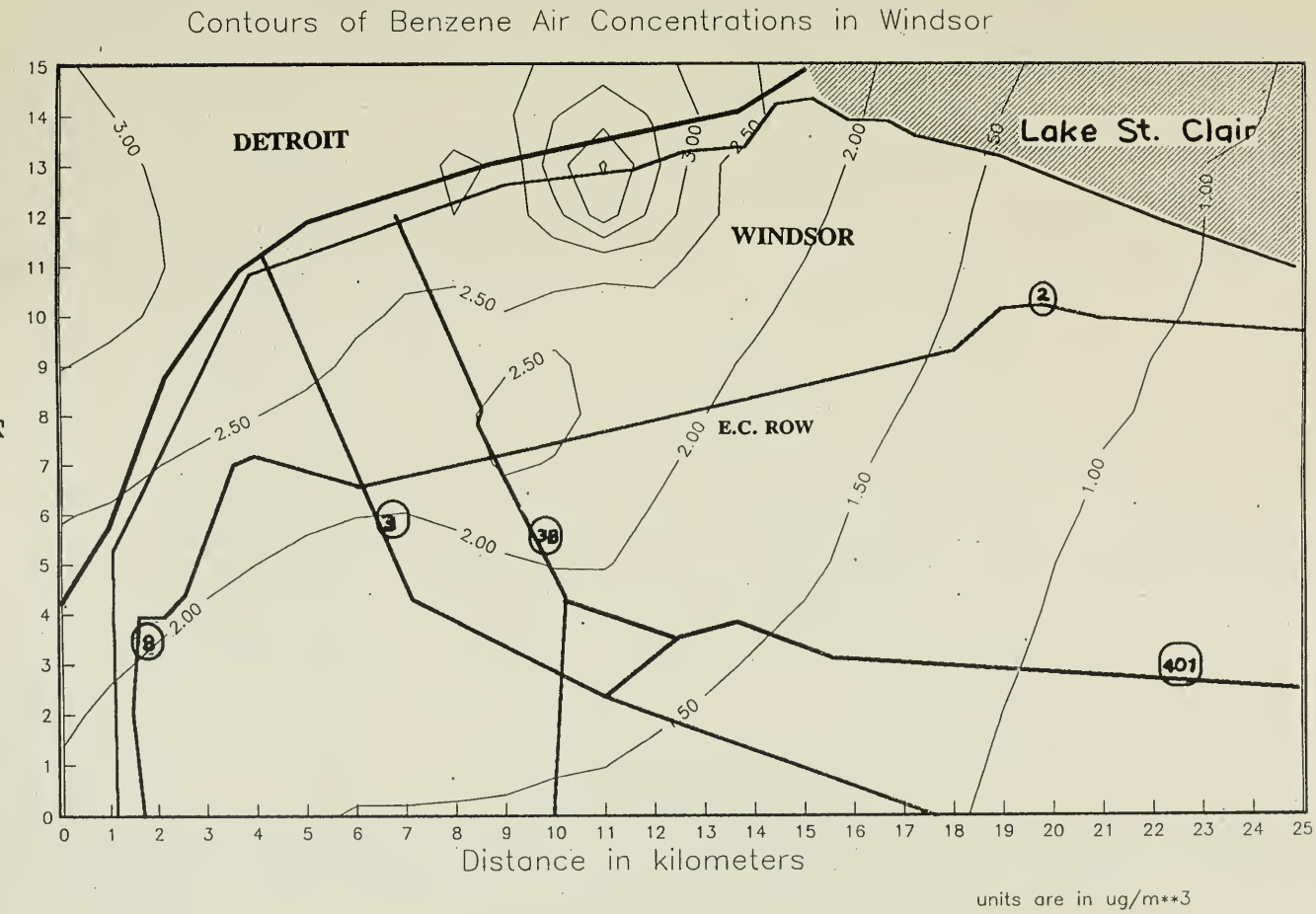



CANADIAN
(10% of total impact)

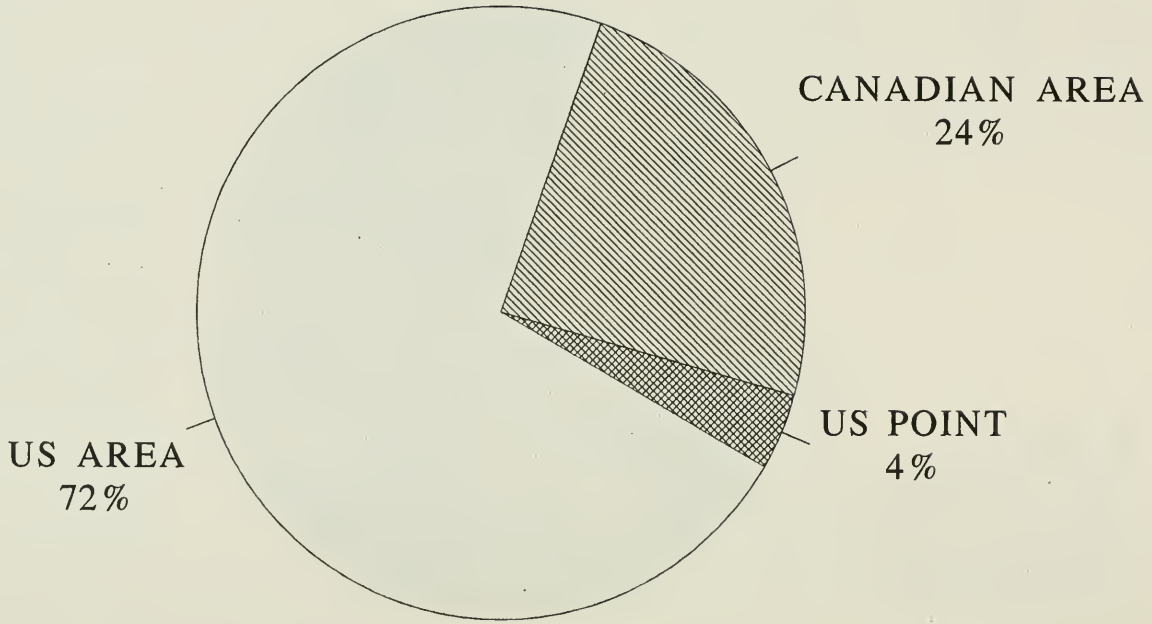



US
(6% of total impact)

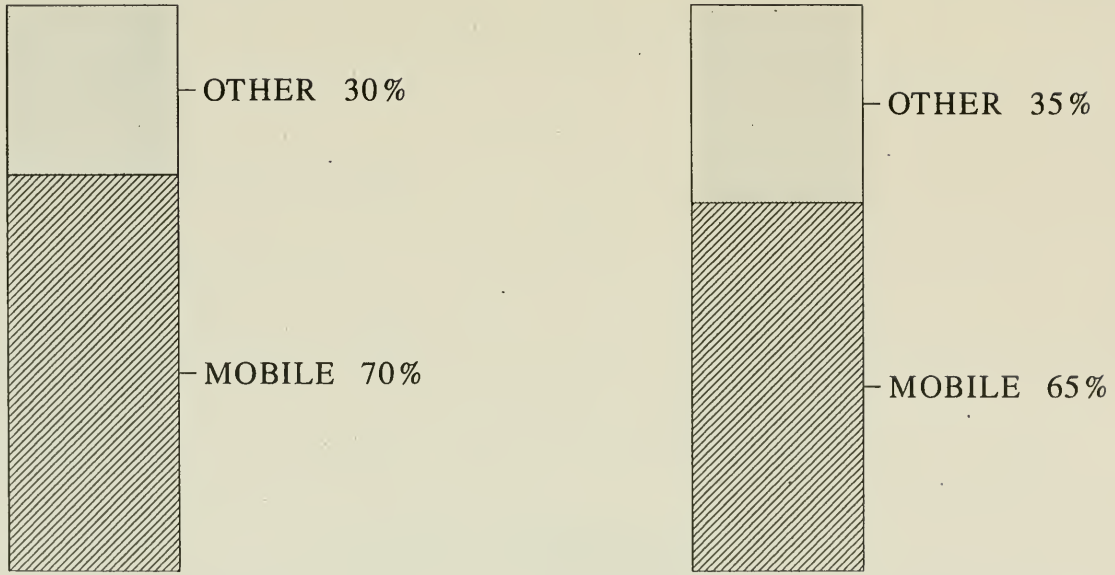
# Fig 5.1.16


Contours of Benzene Air Concentrations in Windsor
DETROIT
WINDSOR
Lake St. Clair
E.C. ROW
3.00
2.50
2.00
1.50
1.00
.50
2
3
3B
401
Distance in kilometers
units are in ug/m**3

# FIG 5.1.17
# AIR CONCENTRATION IMPACT IN WINDSOR
## 1,3 BUTADIENE



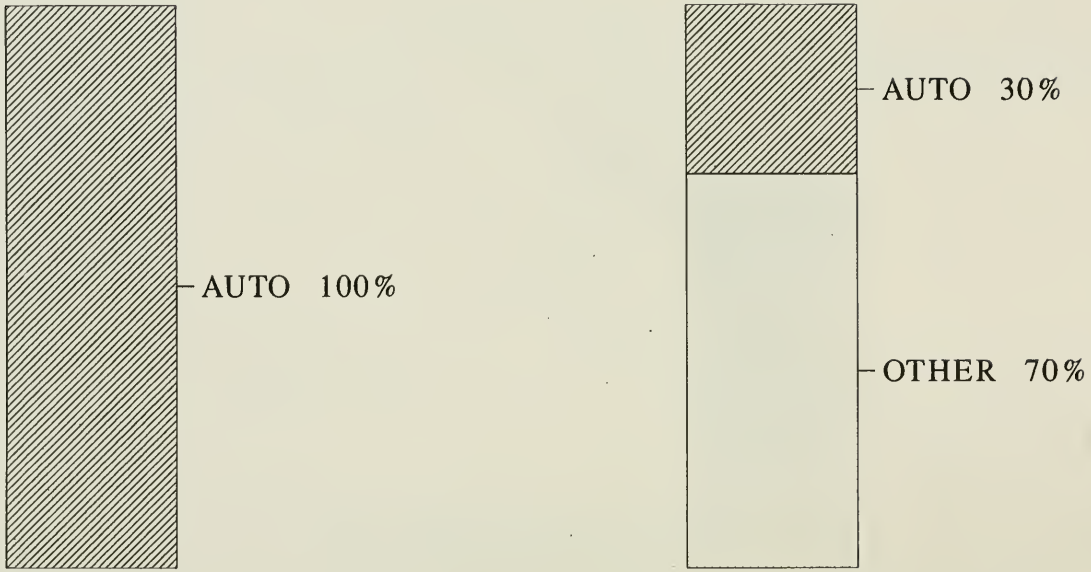
# FIG 5.1.18
# US AND CANADIAN AREA SOURCE SECTORS
## (AIR CONCENTRATION IMPACT IN WINDSOR)
## 1,3 BUTADIENE




CANADIAN
(24% of total impact)

US
(72% of total impact)

# FIG 5.1.19
# US AND CANADIAN POINT SOURCE SECTORS
## (AIR CONCENTRATION IMPACT IN WINDSOR)
## 1,3 BUTADIENE

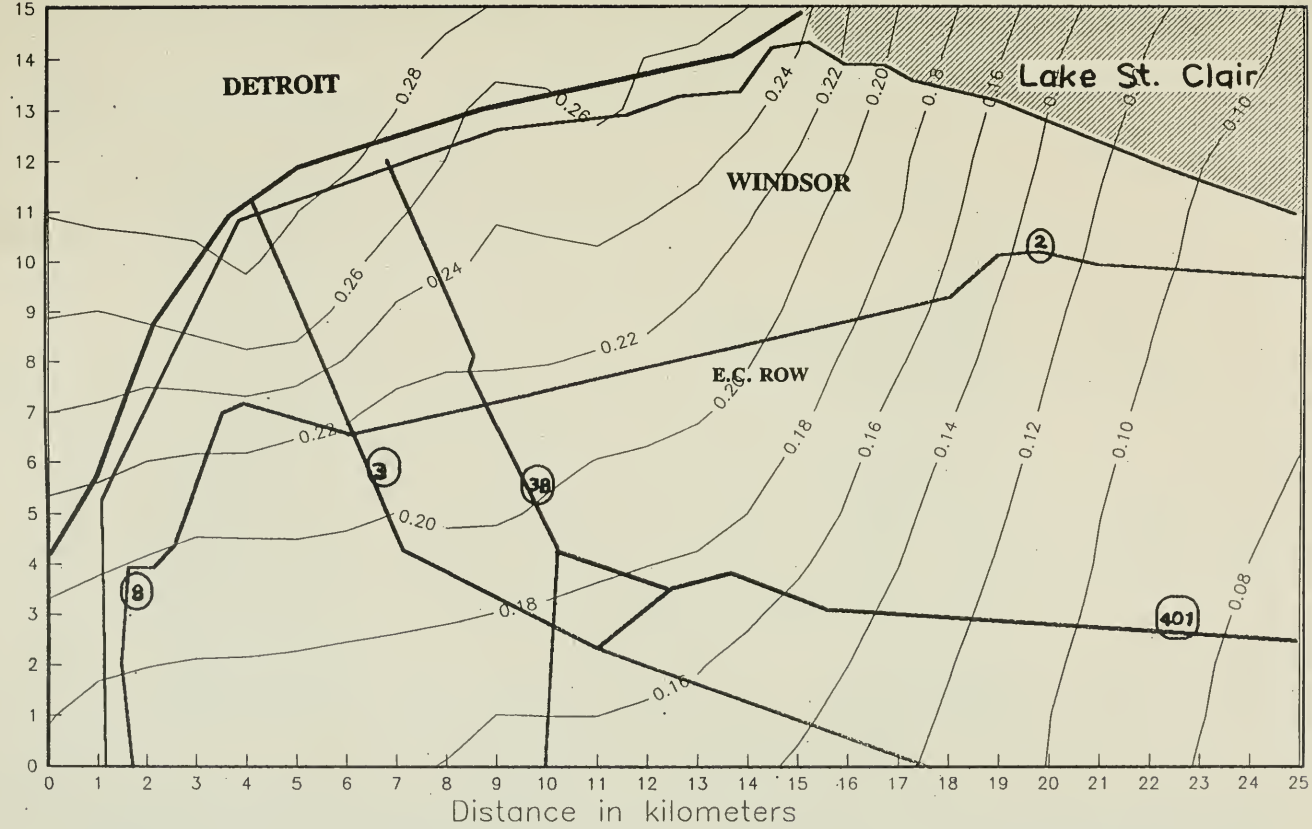



CANADIAN
(< 1% of total impact)

US
(4% of total impact)

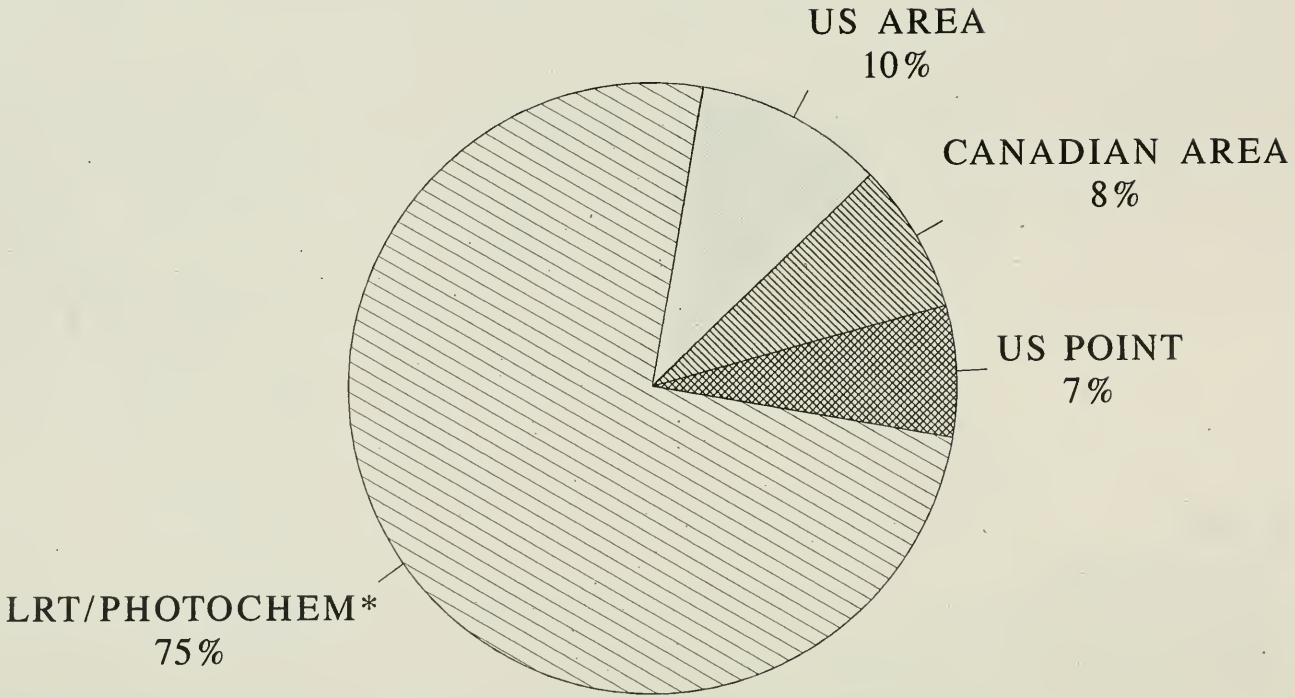
## Fig 5.1.20

Contours of 1–3 Butadiene Air Concentrations in Windsor



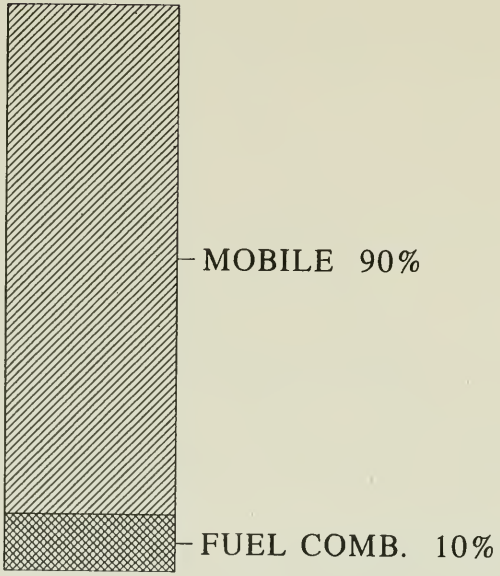

units are in ug/m**3

# FIG 5.1.21
# AIR CONCENTRATION IMPACT IN WINDSOR
## FORMALDEHYDE

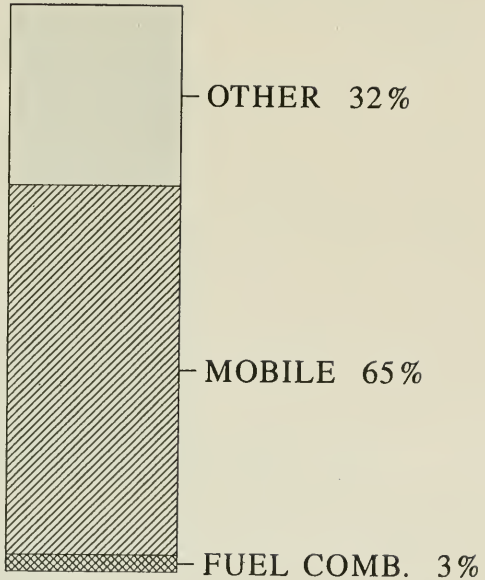



* Long Range Transport / Photochemistry

# FIG 5.1.22
# US AND CANADIAN AREA SOURCE SECTORS (AIR CONCENTRATION IMPACT IN WINDSOR) FORMALDEHYDE

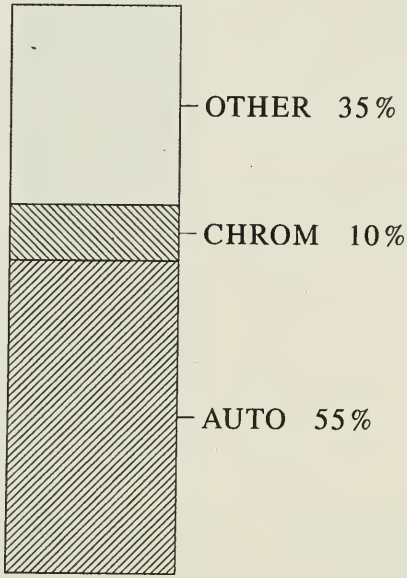



CANADIAN
(8% of total impact)

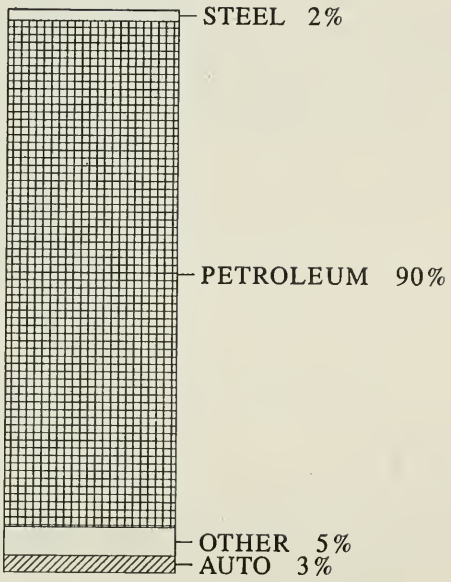



US
(10% of total impact)

# FIG 5.1.23
# US AND CANADIAN POINT SOURCE SECTORS
## (AIR CONCENTRATION IMPACT IN WINDSOR)
## FORMALDEHYDE



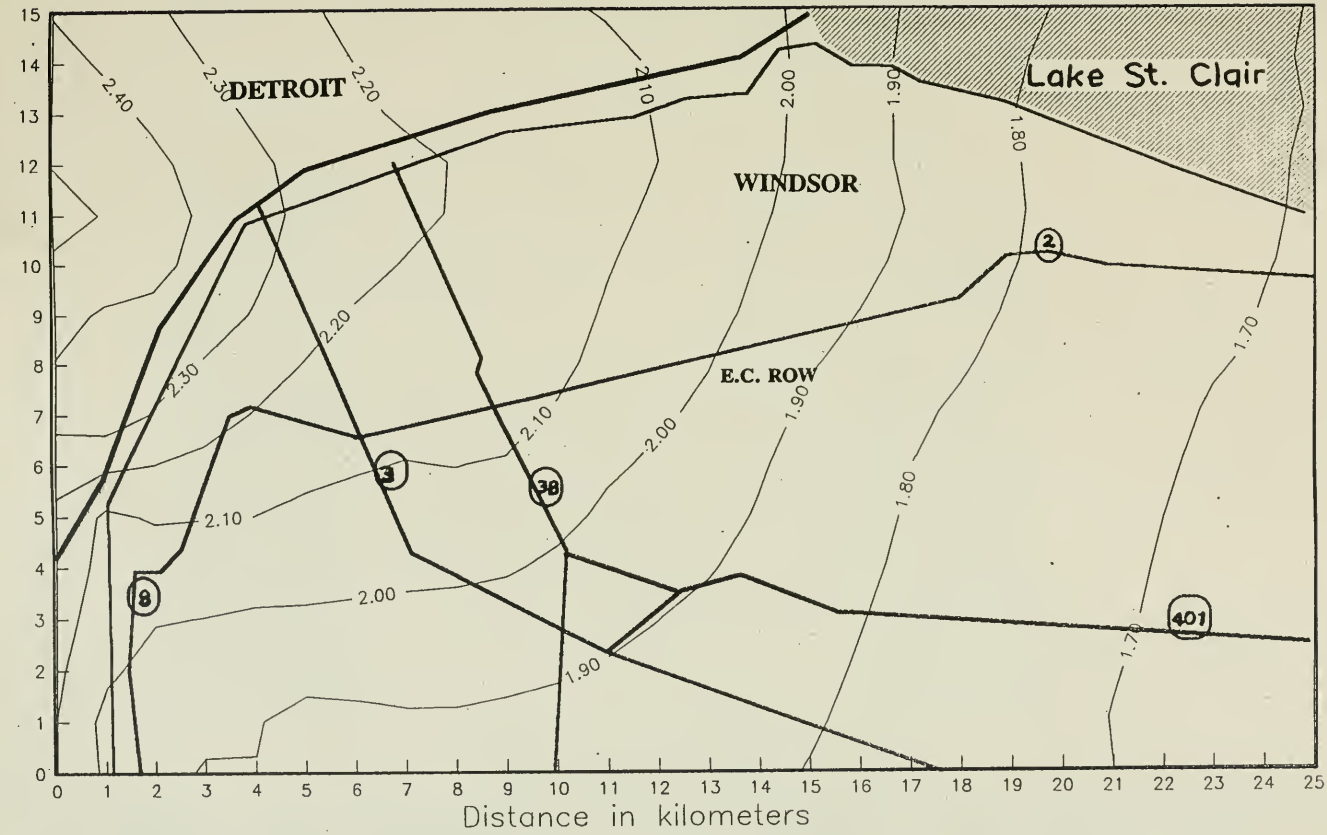

CANADIAN
(< 1% of total impact)




US
(7% of total impact)

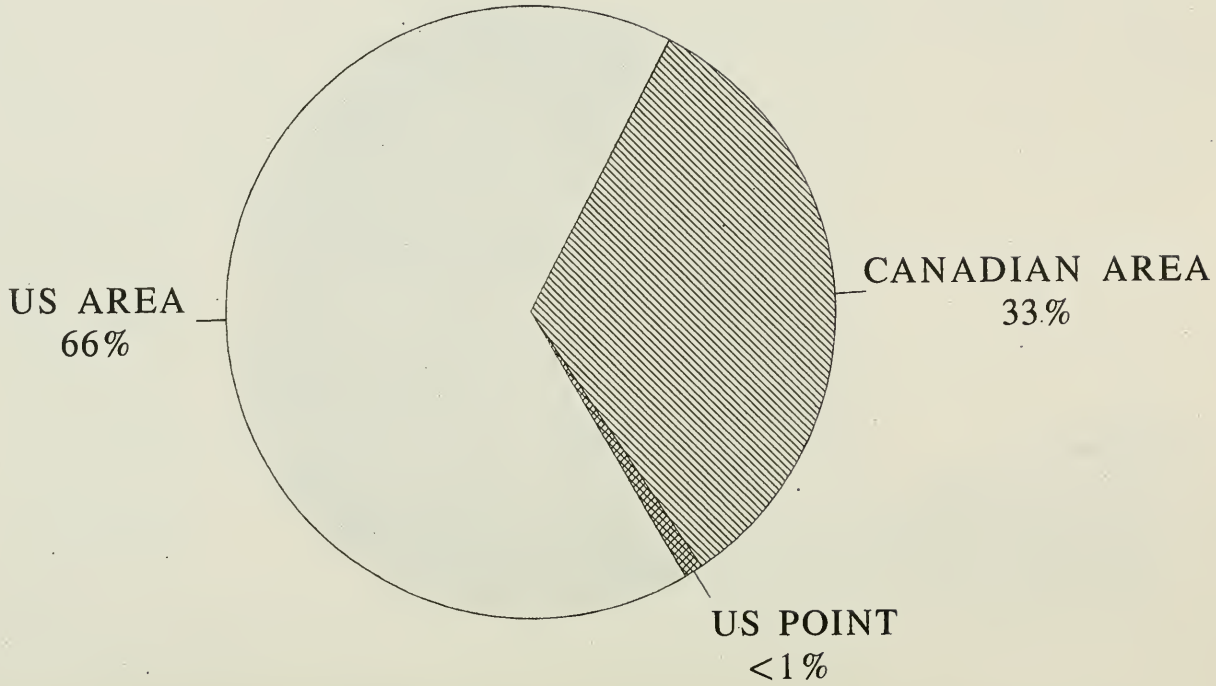
## Fig 5.1.24

Contours of Formaldehyde Air Concentrations in Windsor

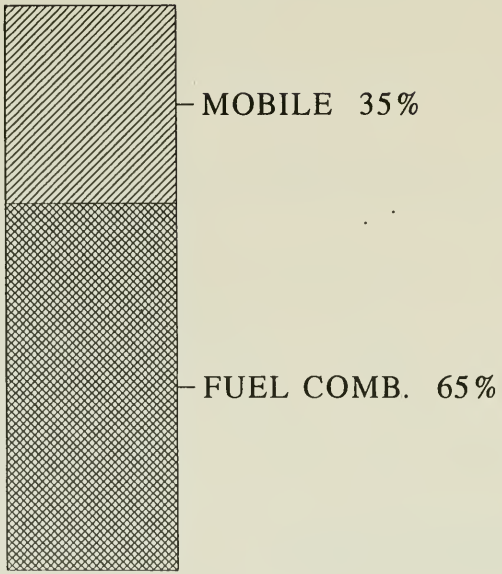



units. are in ug/m**3

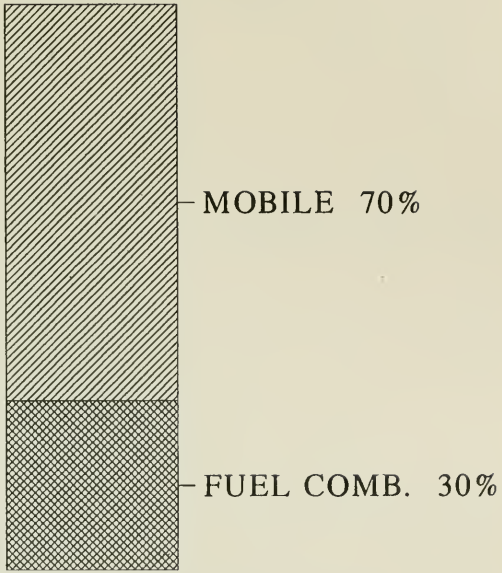
# FIG 5.1.25
# AIR CONCENTRATION IMPACT IN WINDSOR
## BENZO(a)PYRENE



# FIG 5.1.26
# US AND CANADIAN AREA SOURCE SECTORS
## (AIR CONCENTRATION IMPACT IN WINDSOR)
## BENZO(a)PYRENE

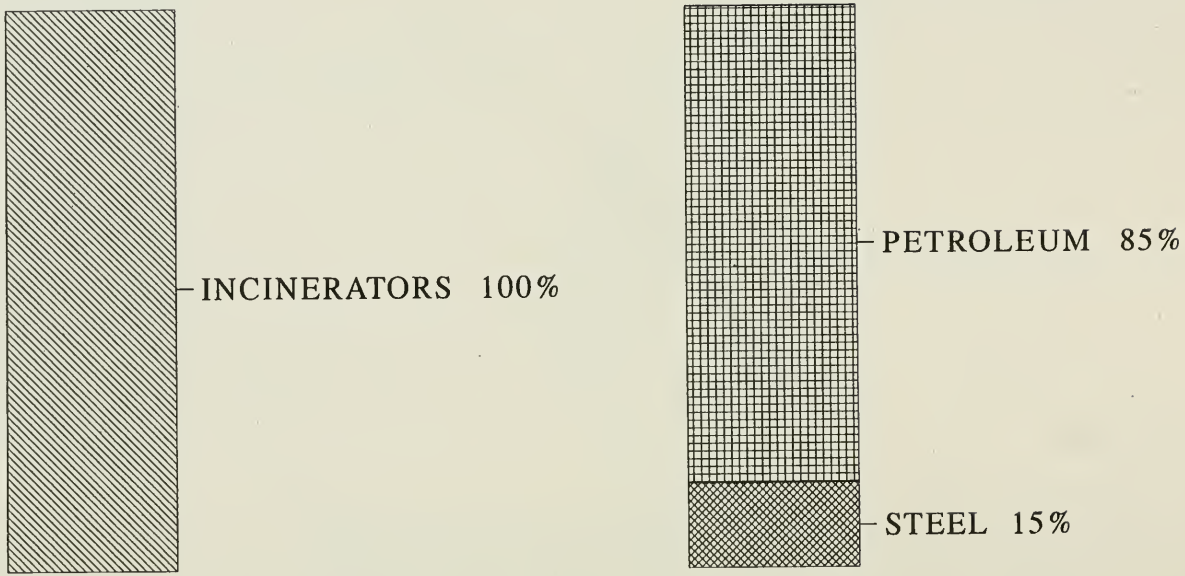



CANADIAN
(33% of total impact)




US
(66% of total impact)

# FIG 5.1.27
# US AND CANADIAN POINT SOURCE SECTORS
# (AIR CONCENTRATION IMPACT IN WINDSOR)
# BENZO(a)PYRENE

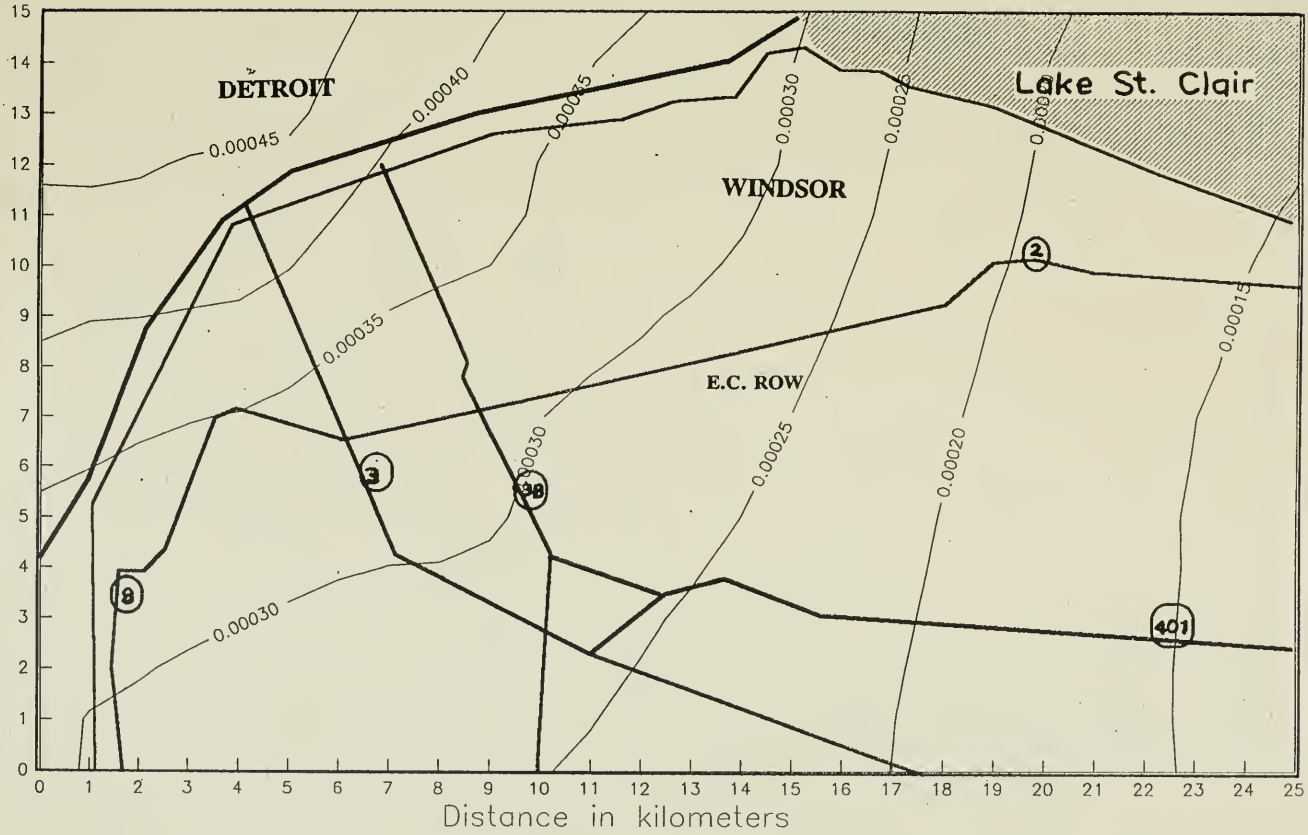



CANADIAN
(< 1% of total impact)

US
(< 1% of total impact)

## Fig 5.1.28

Contours of Benzo (A) Pyrene Air Concentrations in Windsor




units are in ug/m**3